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Extensible Modeling and Simulation Framework (XMSF) 2004 Project Summary Report

by:

Curtis Blais, Don Brutzman, David Drake, Dennis Moen, Katherine Morse, Mark Pullen, and Andreas Tolk

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NAVAL POSTGRADUATE SCHOOL
Monterey, California 93943-5000

RDML Patrick W. Dunne, USN President	Richard Elster Provost

This report was prepared for and funded by the Defense Modeling and Simulation Office (DMSO), 1901 N. Beauregard Street, Suite 500, Alexandria, Virginia 22311.

This report was prepared by:

Curtis L. Blais Research Associate Professor	Don Brutzman Associate Professor

Reviewed by:	Released by:
Dr. Rudy Darken MOVES Institute	Leonard A. Ferrari, Ph.D. Associate Provost and Dean of Research

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13. ABSTRACT *(maximum 200 words)*

The Extensible Modeling and Simulation Framework (XMSF) is defined as a composable set of standards, profiles and recommended practices for web-based modeling and simulation. Markup languages based on XML, Internet technologies, and Web services are combining to enable a new generation of distributed M&S applications to emerge, develop and interoperate. The purpose of this task is to develop the technical framework, coordinate with existing public standardization efforts, and demonstrate distributed exemplars of the developed framework.

This report describes work accomplished in 2004 by the XMSF project team consisting of Naval Postgraduate School Modeling, Virtual Environments, and Simulation (MOVES) Institute, George Mason University (GMU), Science Applications International Corporation (SAIC), and Old Dominion University/Virginia Modeling, Analysis, and Simulation Center (ODU/VMASC). Principal areas of work included ongoing community education and development activities through conference and workshop participation, liaison with relevant standards organizations, and development of exemplar applications demonstrating the technical approaches and applicable standards relevant to XMSF precepts. The report proposes follow-on efforts for 2005, including continuation of current efforts and further standardization work with multicasting, web-enabled IEEE 1516 Run-Time Infrastructure, data modeling in C2 and M&S systems, and executable architectures

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EXECUTIVE SUMMARY

The Extensible Modeling and Simulation Framework (XMSF) project started in April 2002 with seed funding from the Defense Modeling and Simulation Office (DMSO). The effort kicked off with a series of workshops bringing together technical and program management personnel across a broad number of agencies and organizations to investigate the application of web-based technologies, including the Extensible Markup Language (XML) for data modeling and Web services for composable simulation capabilities, to meet military modeling and simulation (M&S) technical challenges. DMSO continues to be the principal sponsor and funding source for the project; however, several efforts initially proposed or developed as XMSF exemplars have received separate funding from various organizations, such as the Joint Forces Command (JFCOM), the Defense Threat Reduction Agency (DTRA), and commercial partners.

XMSF is defined as a composable set of standards, profiles and recommended practices for web-based modeling and simulation. Markup languages based on XML, Internet technologies, and Web services are combining to enable a new generation of distributed M&S applications to emerge, develop and interoperate. The purpose of this task is to develop the technical framework, coordinate with existing public standardization efforts, and demonstrate distributed exemplars of the developed framework.

Principal activities in 2004 included:

- Identification and prioritization of candidate standards for potential adoption by the DoD M&S community. XMSF partners have created strong technical relationships with several key standards organizations, including the World Wide Web Consortium (W3C), the Object Management Group (OMG), the Open Geospatial Consortium (OGC), the Simulation Interoperability and Standards Organization (SISO), the Web3D Consortium, the Internet Engineering Task Force (IETF), the Web-enabled Simulation Consortium (WebSim), and the High Level Architecture (HLA) Technical Support Team.
- Preparation and conduct of experiments to determine and demonstrate the applicability of the candidate standards to meet the needs of the DoD M&S community. Efforts culminated in multiple demonstrations, presentations, and discussions at the 2004 Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) in December 2004.
- Contribution to the discussions of the future of M&S in the Global Information Grid (GIG) environment and its M&S Community of Interest (COI), by presentations of related efforts and concepts during conferences and workshops, including the Simulation Interoperability Workshops, the Command and Control Research and Technology Symposium, the NATO M&S Conference, and a tutorial on this topic during the I/ITSEC 2004.
- Creation of an open source prototype overlay multicast system with embedded performance monitoring, capable of supporting typical distributed simulation performance over the Internet. The partners maintained a laboratory capability to support the testing of this technology over a wide area network.
- Refinement of the Selectively Reliable Multicast Protocol (SRMP) standard for

acceptance by the IETF. Demonstration of overlay multicast working with SRMP in support of distributed simulation.

- Definition and prototypical implementation of C2IEDM based web services for data mediation and storage and retrieval in environments compatible to the Multilateral Interoperability Programme (MIP).
- Preparation and publishing of workshop and conference papers, some in refereed proceedings and refereed journals, describing and promoting adoption of the work.

One of the principal non-DMSO funded XMSF exemplars promoted during the year was the Experimentation Command and Control Interface (XC2I). XC2I includes definition of an XML-based, C2-specific web services interest management (WSIM) language. While some aspects of this language are domain specific (e.g., use of order of battle information for aggregation and disaggregation), it mainly incorporates some new concepts such as spatial-temporal filters that further reduce data flow in bandwidth-constrained environments such as the Internet. This effort is comparable to the data distribution services for the HLA Runtime Infrastructure but is applied in the general context of service oriented architectures. An important result of this work is identification of the need to define a consistent approach combining Web services and streaming multicast for high-volume state delivery in distributed simulations.

On the basis of work performed in 2004, the following efforts are recommended for 2005:

- Continue development of relationships with current and additional standards organizations key to widespread adoption of XMSF concepts in the military M&S community. Focus on continuation of the SISO XMSF Profile Study Group's work to develop a profile standard. Increase attention to encouraging new adopters to experiment with XMSF technologies and the emerging profile standard, and to provide their lessons learned back to the Profile SG. Encourage experimenters to submit exemplars to the testbed to support a virtual 2005 round up demo. In addition, the XMSF partners will continue in leadership/liaison roles in IETF, OMG and Web3D/W3C including Web3D XMSF Working Group; WebSim, a consortium of OMG, Web3D, SISO, and OGC; and SISO SG.
- From the management side, overlay multicast will need continued attention to obtain standards body acceptance. Current work to employ XOM in a JFCOM federation will help to build an experience base for promotion of the concept; however, a greater breadth of experience and a continued involvement in the IETF standards process will be required for at least one year and possibly two years. This should be pursued in conjunction with the IETF liaison role. From the technical side, continue to refine the SRMP standard for acceptance by the IETF, based on overlay multicast working with SRMP in support of distributed simulation. Recent interest within Web3D for use of XOM can help to build this case.
- Complete integration of a web enabled IEEE 1516 RTI into an overlay multicast network environment (using 2004 funding not yet on contract). Expand this to a compelling demonstration using the Xj3D viewer and/or the latest version of the JFCOM web viewer.
- Continue to inform the M&S community through conference and workshop participation

in the form of technical papers, online and live tutorials, and presentations.

- Develop a proposed approach to multicasting that is compatible with Web services. Extend the work into the emerging publish-subscribe Web technologies and standards. Promote the streaming standard and XML compression techniques that are its natural companion, allowing high-performance tagged streams of data to be passed across simulations and C4I systems.
- Focus the XMSF Distributed Testbed in 2005 on experiments in use of a pilot registry for semantic interoperation of existing simulation and C4I software. This process will yield essential understanding of support for composability and also will help to advise the ongoing process of assembling the M&S Namespace. The partners will provide focused leadership and participate in development to determine an initial, minimal set of metadata tags, to experiment with tools and supporting algorithms that would use the metadata tags on components in a registry to find suitable components, and to align data models via technologies such as XSLT.
- Extend WSIM work from XC2I to create a general purpose web services interest management language. This language will be mappable to IEEE 1516 Data Distribution Management (DDM). An open-source test implementation and its source code will be hosted in the testbed, in a manner compatible with Overlay Multicast and XMSF Registries.
- Transform the Command and Control Information Exchange Data Model (C2IEDM) into three XML based versions (logical data model, physical data model, documentation) and map the IDEF1X extension rules to XML extension rules. Conduct two invited expert workshops to conduct this task and present the results to the community. Provide an exemplar C2IEDM tactical application (e.g., TOPTIVA from the Naval Undersea Warfare Center) and examine strategies for a C2IEDM Semantic Web service.
- Distribute the C2IEDM web services for data mediation and data storage and retrieval within the international military M&S community as a basis for common and aligned design of application and extension rules. This operational international effort should be aligned with the C2IEDM Semantic Web service efforts.
- Continue management and enhancement of an XMSF distributed testbed for distributed proof-of-principle and technology demonstrations. The focus is on providing continuous availability of Web services/servers supporting broad experimentation with XMSF profiles.
- Through articles and papers, show the potential of software engineering concepts, such as the Model Driven Architecture (MDA), to compose simulations in a System of Systems Environment applicable to global grids, the Global Information Grid (GIG), and other service oriented environments.
- Create an exemplar design in the domain of executable architectures to show applicability to XMSF of this emerging field.
- Continue to coordinate efforts with DMSO through frequent technical and management interactions and periodic progress reporting.

Overall, the project continues to make exceptional progress in promoting web-based concepts to

the military M&S community as witnessed by the increasing number of papers, activities, and program concepts at DMSO and other agencies, such as JFCOM and DTRA, employing these concepts.

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1 INTRODUCTION

1.1 Background

The Extensible Modeling and Simulation Framework (XMSF) is a composable set of standards, profiles and recommended practices for web-based modeling and simulation. Markup languages based on XML, Internet technologies, and Web services will enable a new generation of distributed modeling and simulation applications to emerge, develop and interoperate. The purpose of this task is to develop the technical framework, coordinate with existing public standardization efforts, and demonstrate distributed exemplars of the developed framework.

The XMSF project started in April 2002 with seed funding from the Defense Modeling and Simulation Office (DMSO). The effort kicked off with a series of workshops bringing together technical and program management personnel across a broad number of agencies and organizations. The findings of the initial workshops are documented in (Brutzman, et. al., 2002). DMSO continues to be the principal sponsor and funding source for the project; however, several efforts initially proposed or developed as XMSF exemplars have received separate funding from various organizations, such as the Joint Forces Command (JFCOM) and the Defense Threat Reduction Agency (DTRA).

The XMSF project team consists of academic and corporate partners; specifically: the Naval Postgraduate School (NPS) Modeling, Virtual Environments and Simulation (MOVES) Institute; George Mason University (GMU); Science Applications International Corporation (SAIC); Old Dominion University (ODU) Virginia Modeling, Analysis, and Simulation Center (VMASC).

1.2 Objective

Specific requirements from the project Statement of Work (SOW) for 2004 are stated below:

- Start of Work teleconference, to be scheduled by the Contractor as mutually agreed with the Contracting Agency's Contracting Officer's Representative (COR) and DMSO.
  - The purpose of the conference is to ensure a complete understanding of the requirements by both the Government and the Contractor.
  - As part of the conference, the contractor shall provide a chart depicting their projection of the expenditure of the available funding over the period of performance of the project.
  - The projection is for planning purposes only and will not be used to control the execution of the work.
  - Prepare and deliver minutes of the start of work teleconference.
- Prepare a Monthly Financial Status and Progress Report. This report shall summarize work accomplished during each reporting period, to include:
  - The results of In Progress Reviews (IPRs) and meetings
  - Resources consumed to accomplish the work (labor hours by category and total cost, travel and costs, and other direct costs)
  - Work planned for the next reporting period and an estimate of resources required

    to accomplish that work (detailing labor hours by category and total cost, travel and costs, and other direct costs)

    - An overall status of resources, approved equipment/materials procured, and status of all deliverables.
    - If applicable, highlight any potential issues with respect to completing the work as contracted (e.g., potential resource shortfalls, schedule slips).

- Identify and prioritize a list of candidate standards for potential adoption by the DoD modeling and simulation community.
    - Include an assessment of the utility of each standard and the likelihood of it meeting the needs of the DoD in the short term (1-3 years), mid-term (4-6 years), or long term (7+ years).
    - The list shall identify the specific team member responsible for each specific standards effort.
        - Each responsible member will provide DMSO with a report describing the specific standard, its area of applicability to the DoD M&S community to include identification of the standard or standards it will replace, an assessment of its maturity and required changes and a timetable for the adoption of those changes.
        - Establish a liaison with the appropriate standards organizations and represent the requirements of the DoD modeling and simulation community within that organization.
    - Conduct experiments to determine and demonstrate the applicability of the candidate standards to meet the needs of the DoD modeling and simulation community.
    - Demonstrate the use of the candidate standards in an environment to be coordinated with and approved by DMSO.
        - These demonstrations shall be designed to replicate the rigorous demands of the DoD M&S community.
        - A report of demonstration results shall be delivered within 45 days of the conclusion of the event and shall contain a recommendation for or against adoption of the standard by the DoD.
    - Maintain liaison with the DoD High Level Architecture (HLA) program and provide representation to the HLA Technical Support Team and the IEEE 1516 standards revision process.
- Create an open source prototype overlay multicast system with embedded performance monitoring, capable of supporting typical distributed simulation performance over the internet. Maintain a laboratory capability to support the testing of this technology over a wide area network.
- Continue to refine the Selectively Reliable Multicast Protocol (SRMP) standard for acceptance by the IETF. Demonstrate overlay multicast working with SRMP in support

of distributed simulation.

- Integrate a web enabled IEEE 1516 RTI into an overlay multicast network environment using the latest version of the JFCOM web viewer.
- Produce conference papers in support of the work.

In addition to the core DMSO funding, various related projects funded by other organizations contributed to the results summarized in this report. The funding was not limited to government organizations; industry partners contributed research and development funds for XMSF efforts as well.

1.3 Document Organization

Chapter 1 of this document provides an introduction to the work tasked by DMSO to the XMSF project. Chapter 2 describes project management activities performed during the year, including technical reporting and task planning for calendar year 2005. Financial data is provided in a separate limited distribution version of this document (NPS-MV-05-001PR), controlled by DMSO. Chapter 3 identifies candidate standards and standards bodies for engagement in the XMSF project. Chapter 4 addresses technical work performed on the XMSF Overlay Multicast capability. Chapter 5 discusses work relating to the Web-enabled Run-Time Infrastructure (WE-RTI) and its employment in the Experimentation Command and Control Interface (XC2I) project funded by JFCOM. Chapter 6 summarizes efforts completed during the year for community education and outreach, including conference papers and presentations, tutorials, workshops, and other activities. References and a Glossary of Terms and Acronyms are provided at the end of the report.

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2 PROJECT MANAGMENT

2.1 Project Year 2004

Funding at the start of FY04 consisted of carry-over funds from FY03 that had been placed with partner organizations GMU and SAIC, and interim funding to NPS received at the start of FY04 (Oct-Dec 2003) to support activities through the 2003 Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC). Primary FY04 funding was received in March 2004.

Principal XMSF funding was provided by DMSO to NPS for management and distribution to the partner organizations in March 2004. While portions allocated to educational partners GMU and ODU/VMASC were put in place very quickly through the Open Market Corridor contracting vehicle (http://www.omchub.com), the portion allocated to SAIC had to be placed through General Services Administration (GSA), requiring an open competition. The funding has been obligated to GSA since the start of that process (July 2004), but the contract was not awarded to SAIC until 24 February 2005 creating serious delays in the efforts planned for 2004.[1] The end date of the contract to GMU has been extended to allow some additional time for coordination of their effort with SAIC's efforts when the GSA contract is finally awarded (however, the contract vehicle limits the period of performance to one year from the date of award in May 2004, so the extension only added two weeks to the current effort).

2.2 Progress Reporting

The following provides a brief summary of the technical progress in 2004 against the project requirements delineated in Section 1 refer to sections 3-6 in this document for detailed information on the work performed):

- **Requirement**: Start of work teleconference.
  Action: Completed the requirement in weekly telephone conferences in March/April 2004 (minutes of all XMSF project meetings have been made available through the project reflector: xmsf-management@movesinstitute.org). Prepared and delivered a presentation on XMSF Support to Long Term M&S Community Objectives with a strategy for near term (FY05) project goals and funding requirements.
- **Requirement**: Monthly financial status reports.
  Action: Reports were prepared and delivered through November 2004. Full financial data is provided in the companion limited distribution version of this report (NPS-MV-05-001PR) available through DMSO.
- **Requirement**: Prioritized list of candidate standards for potential adoption by the DoD M&S community. Also include assessment of the standards utility and likelihood of it meeting the needs of the DoD in the short term (1-3 years), mid-term (4-6 years), and long-term (7+ years). The list must identify the specific team member responsible for each specific standards effort.
  Action: Areas of standards development have been identified and liaisons established – refer to the discussion in Section 3.

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1 Unfortunately, the GSA contracting representative assigned to the work became ill in December and passed away in late January. New personnel were assigned to the paperwork and completed the processing as quickly as possible.

- **Requirement**: Each team member responsible for a specific standards effort must provide DMSO a report describing the specific standard, its area of applicability to the DoD M&S community to include identification of the standard or standards it will replace, an assessment of its maturity and required changes and a timetable for the adoption of those changes.
Action: Refer to Section 3 of this report.
- **Requirement**: Demonstrate the use of the candidate standards in an environment to be coordinated with and approved by DMSO.
Action: Numerous demonstrations were presented at the 2004 I/ITSEC, including Web services for analytical model interconnection and XC2I communications, AUV Workbench, Viskit graphical user interface for constructing discrete event simulation models, XMSF Overlay Multicast (XOM) with both IEEE 1516 HLA/RTI and Web Services Interest Management, X3D web-based graphics, and others. This project summary document provides a description of I/ITSEC activities to meet requirements for a report on demonstration results within 45 days of the event. I/ITSEC demonstrations are identified in Section 3.2.
- **Requirement**: Provide representation on the HLA Technical Support Team and as part of the HLA IEEE 1516 standards revision.
Action: SAIC has provided ongoing representation for these activities, although activity has been hampered by contracting difficulties in the latter half of the 2004 calendar year.
- **Requirement**: Develop and demonstrate an overlay multicast network (XOM) capable of supporting actual simulation performance requirements over the Internet. Maintain a laboratory capability to support testing of this technology over a wide area network.
Action: GMU (including Denny Moen's dissertation research) is the lead organization for development of XOM capabilities. A draft interim report on the architecture has been distributed for review and comment in December 2004; also refer to Section 4 of the present document. In addition to the I/ITSEC demonstration described above, on 19 November 2004, Dr. Pullen led an online "deep-dive" tutorial presentation using the Network EducationWare (NEW) collaboration software (see tutorial announcement below). The presentation was recorded and is available for online viewing. NPS (design and prototype development) and SAIC (demonstration and evaluation) are contributing to this effort.

    Overlay Multicast and its Application for Advanced Distributed Simulation: Growing demand for use of Internet/Web-based services in large scale real-time distributed virtual simulation (RT-DVS) systems and other real-time applications is fueling extensive interest in overlay multicast protocols. These applications demand Quality of Service (QoS) and many-to-many multicast services that are not available in underlying Internet services today and are not likely to be offered as an open network service in the near future. This presentation describes implementation of an overlay multicast protocol designed to support many-to-many multicast for RT-DVS applications, called Extensible Modeling and Simulation Framework Overlay Multicast (XOM). Focus will include the architecture and key design considerations of XOM, as well as preliminary results from laboratory experiments with our prototype, which will be available for download on our website. Recorded delivery via Network EducationWare

(http://netlab.gmu.edu/xmsf); click on "conference logon". To obtain an account, send email to help@netlab.gmu.edu

- **Requirement**: Continue to refine the Selectively Reliable Multicast Protocol standard for acceptance by the IETF (GMU lead).
  Action: Internet Draft draft-pullen-srmp-05.txt submitted by GMU is pending review by the IETF Reliable Multicast Working Group chair. Refer to the discussion in Section 4.
- **Requirement**: Integrate a web enabled IEEE 1516 RTI into an overlay multicast network environment using the latest version of the JFCOM web viewer (SAIC lead). Refer to the discussion in Section 5.
  Action: An initial capability was included in the I/ITSEC demonstration described above; however it is our goal to complete a more substantial demonstration in work pending award of the GSA contract to SAIC.
- **Requirement**: Submit all conference papers two weeks prior to the published deadline for DMSO review and release approval.
  Action: See Section 6 for a listing of all papers, presentations, and tutorials from 2004 work activities.

2.3 Objective-Driven Tasking

In mid-FY04 the XMSF partners prepared and presented to DMSO a presentation describing XMSF support of long term M&S community objectives covering the following topics:

- Long Term M&S Community Objectives
- Policy Impacts and Influences
- Enabling Capabilities
- FY05 XMSF Tasking

The following M&S community objectives were identified:

- Broad DoD and Allied Support
  - Goal
    - Recommended Standards and Methods are applied within the U.S. DoD as well as in the respective allied counterparts, in particular NATO
  - Measures of Success
    - Recommended Standards and Methods are incorporated into the Combined and Joint Operational Architectures, such as the Joint Technical Architecture (JTA) and/or NATO C3 Architecture
    - Recommended Standards and Methods are part of the Code of Best Practices applied in the departments
  - Identify Stakeholders
    - U.S. DoD, Office of the Secretary of Defense (OSD), Assistant Secretary of Defense National Information Infrastructure (ASD NII), Defense Information Systems Agency (DISA), DMSO, M&S Offices of the Services; NATO Consultation, Command and Control Agency (NC3A) (Branches for C3I and M&S)
- Integrated IT Environment Supporting the Warfighter
  - Goal
    - Seamless delivery of operationally required functionality within an integrated

        - Information Technology (IT) environment based on heterogeneous components
    - Measures of Success
        - Number of operationally required functions within repositories
        - Degree of reuse of functions delivered by components
        - Number of organizations participating in the function sharing repositories
        - Seamless integration of M&S and C4I IT
    - Identify Stakeholders
        - DMSO, DISA, and their counterparts in the services and allied organizations
- M&S Support of Military Operations
    - Goal
        - Operational use of M&S functionality via tactical systems to support all phases of military operations, including training, planning, analysis of alternatives, rehearsal, execution, and de-briefing and evaluation (after action review and analyses)
    - Measures of Success
        - M&S functionality applied in tactical/operational C4I systems
        - Degree of operationally required data alignment
        - Degree of M&S functionality in the Mission-to-Means Framework (MMF)
    - Identify Stakeholders
        - DMSO, DISA, and counterparts in the services and allied organizations
- M&S Support of Life Cycle Functions
    - Goal
        - Capitalizing on M&S tools and technologies to deal with system development, operational readiness, and life cycle cost
        - This is accomplished through the collaborative efforts of the requirements, training, operations, and acquisition communities, as in the Army Simulation, Modeling, Acquisition, Requirements, and Training (SMART) Vision
    - Measures of Success
        - M&S tools used for all phases of the life cycle, from requirements analysis to design, procurement, introduction, operational use, to replacement and retirement
    - Identify Stakeholders
        - Acquisition and procurement agencies and organizations of the services and allies, including Conference of National Armaments Directors (CNAD)

The plan identified several potential policy impacts and influences, including:

- Reference Models
- Meta Data and Meta Modeling
- Open Standards
- Open Source versus Intellectual Property (IP) issues
- DoD Architecture Framework
    - Joint Technical Architecture
- DoD M&S Master Plan
    - HLA
- Net-Centric Enterprise Services (NCES) & Global Information Grid (GIG)
- JFCOM J7/J8/J9 policies
- Other CINC policies (e.g. STRATCOM)

- Allied/coalition policies

The GIG program is organized around a number of Communities of Interest (COIs). The XMSF team proposed formation of an M&S GIG COI. The DoD M&S COI was officially established by a Memo to the Director, Information Management, OASD (NII) from the Director of the Defense Modeling & Simulation Office (DMSO) on 10 June 2004. The following provides additional information about progress in this regard:

- M&S COI for the GIG is now in process of formation
  - High-level DMSO-DISA agreement
  - Namespace is critical to effective XMSF deployment
- Opportunity to create effective C4I-Simulation links in DISA's Network Centric Capabilities Pilot (NCCP)
  - ASD(NII) program to demonstrate breaking down stovepipes
  - Displays C4I best-of-breed Web services
  - Opportunity to show effectiveness of M&S Web services
- XMSF HF goals:
  - August 04: provide context for simulation such as JFCOM's Joint Urban Operations with an early XC2I prototype
  - August 05: operate XBML and XC2I using real C4I system feeds
- Affects long term community objective
  - Integrated C4I environment with simulation tools supporting military operations

To achieve objectives of the XMSF program, a number of enabling capabilities must be established or solidified, including:

- Simulation Interoperability Support
  - Supporting Technologies
    - XMSF core technologies:
      - XML, Simple Object Access Protocol (SOAP), Hyper Text Transfer Protocol (HTTP), Internet Protocol
    - Registries and repositories
      - M&S namespace, Web Services Description Language (WSDL), Business Process Execution Language for Web Services (BPEL4WS), Web Ontology Language (OWL)
    - Composability support
      - Metadata, Conceptual modeling language
    - Currently deployed frameworks and technologies
      - Test and Training Enabling Architecture (TENA) (HLA & others), Distributed Continuous Experimentation Environment (DCEE) (HLA & DIS), Joint National Training Center (JNTC) (HLA & DIS), Web-Enabled Run-Time Infrastructure (WE RTI)
  - Supporting Methods
    - XMSF Profiles
      - Concept of Operations
    - Federation Development and Execution Process (FEDEP)
    - Open standards and open source
- Full Interoperation of M&S and C4I Web Services

- Supporting Technologies
    - Common communication protocols enable physical connectivity
    - Common meta-management tools enable sharing of mapping information
- Supporting Methods
    - Common methods for metadata management (semantic interoperability)
    - Common methods for metamodel management (pragmatic/dynamic interoperability)
    - Common conceptual models/common concept of the mission space (conceptual interoperability)
    - Shared management councils/advisors /standards bodies

- Tactical Ontologies
  - Supporting Technologies
    - XML, XML-Schema for defining common vocabularies
    - XML Stylesheet Language for Transformation (XSLT) for language interchange
    - Resource Definition Framework (RDF), RDF Schemas (RDF-S), DARPA Agent Markup Language and Ontology Inference Layer (DAML+OIL), OWL and other emerging Semantic Web standards and techniques for defining common ontologies
    - Knowledge Representation
  - Supporting Methods
    - Composability of conceptual models
    - Levels of Conceptual Interoperability and Model-Based Data Management
    - Command and Control Information Exchange Data Model (C2IEDM) for multi-national information interoperability
    - Extensible Battle Management Language (XBML) for planning and operations orders
    - Semantic Web Services
- Improved Military Messaging
  - Supporting Technologies
    - XML as a basis for all messaging
      - Improved readability by humans, C4I systems, software agents, robots
      - Message Text Format (MTF) compatibility
      - Improved validity, clarity, correctness, interoperability, and forward compatibility
    - Compressed XML binary now providing smaller message size with improved reliability
    - Forward Error Correction (FEC) unlocks noisy Radio Frequency (RF) and acoustic communications links
    - XML Tactical Chat (XTC)
  - Supporting Methods
    - Formally register allowed vocabularies in DoD registry to make tactical ontologies executable
- Viability of XML-Based Technologies
  - Supporting Technologies
    - Long history and application of mark-up languages (SGML, HTML)
    - Broad and extensive industry adoption

    - Growing numbers of software tools and products
    - Readable by human and software agents
    - Basis for next-generation Semantic Web
  - Supporting Methods
    - W3C and other powerful standards organizations shaping the future of the Web
    - Foundational to all system interoperability developments today
    - License-free and platform-independent
- Common Ground Between Industry and Government
  - Supporting Technologies
    - Web/Internet
    - Discrete event simulation
    - Computer graphics/visualization
    - High performance computers/networks
    - Low-cost distributed computers/networks
    - Wireless networking
    - Public Key Infrastructure (PKI) security
    - Object-oriented languages, especially Java/C++
  - Supporting Methods
    - Object-oriented development
    - Design patterns
    - Rapid prototyping
    - Spiral development
    - Model Driven Architecture (MDA) / Unified Modeling Language (UML)
- Agent Based Technologies
  - Supporting Technologies
    - Artificial Intelligence research
      - Autonomous and cooperating agents
      - Planning
      - Learning
    - Semi-Automated Forces
    - Semantic Web (RDF, DAML+OIL, OWL)
  - Supporting Methods
    - Standardized agent communications languages
    - Frameworks for mobile agents(e.g. CoABS)
    - Human behavior representation

2.4 FY05 Planning

Primary tasks proposed for FY05 are described in the following subparagraphs.

2.4.1 Overlay Multicast Standards

Background: In FY04 GMU worked on an architecture for many-to-many overlay multicast for use with distributed simulation (XOM); also working with the IETF to have SRMP approved as a draft standard.

FY05 work: Overlay multicast will need continued attention to obtain standards body acceptance. Current GMU work with SAIC to employ XOM in a JFCOM federation will help to

build the experience base for this, however a greater breadth of experience and a continued involvement in the IETF standards process will be required for at least one year and possibly two years. There is also high potential for application of XOM in the NCCP. This should be pursued in addition to the IETF liaison role.

Resources: .5 Full-Time Equivalent (FTE) faculty and one graduate student support plus travel to IETF meetings.

2.4.2 Streaming Web Services

Background: A basic tenet of XMSF is the benefit of Web services as a basis for distributed software interoperation. Web services facilitate interoperation because they are easy to create, easy to interface, and easy to compose. However, work for JFCOM has shown that the basic SOAP/HTTP service requires 30 times as much data over the network for unicast transmission, and the Web standards do not provide for multicast (overlay or otherwise) that could improve network efficiency further by orders of magnitude.

FY05 work: GMU has proposed an approach to multicasting that is compatible with Web services. An extension of this approach into the emerging publish-subscribe Web technologies and standards will be required to take advantage of our approach. GMU will promote the streaming standard; NPS will promote the XML compression that is its natural companion, allowing high-performance tagged streams.

Resources: .5 FTE faculty and 2 graduate students GMU; .25 FTE faculty and 1 graduate student NPS, and travel to W3C meetings.

2.4.3 XMSF Registries

Background: One of the most promising aspects of XMSF is the support registries can provide for composable software processes. To date we have not been able to focus on this promise; we don't understand what benefits existing Web technology (UDDI and WSDL) offer and what, if any, additional capabilities are needed in Web standards.

FY05 work: Focus XMSF Distributed Testbed experiments on use of a pilot registry for semantic interoperation of existing simulation and C4I software. This process will yield essential understanding of support for composability and also will help to advise the ongoing process of assembling the M&S Namespace. SAIC will provide focused leadership and participate in development to determine an initial, minimal set of metadata tags, experiment with tools and supporting algorithms that would use the metadata tags on components in a registry to find suitable components, and align their data models via technologies such as XSLT.

Resources: .25 FTE and two graduate students each at NPS, ODU, GMU, 1.75 FTE at SAIC.

2.4.4 Web Services Interest Management Language

Background: In support of XC2I, SAIC has defined an XML-based, C2-specific web services interest management (WSIM) language. While this language is domain specific, it incorporates some new concepts such as temporal filters that will further reduce data flow in bandwidth constrained environments such as the Internet.

FY05 work: SAIC will extend previous work on WSIM from XC2I to a general purpose web services interest management language. This language will be mappable to IEEE 1516 DDM. An open-source test implementation and its source code will be hosted in the testbed, in a manner compatible with Overlay Multicast and XMSF Registries.

Resources: 1 FTE for SAIC

2.4.5 XML Namespace and Mediation Support

2.4.5.1 XML C2IEDM Framework

Background: The Command and Control Information Exchange Data Model (C2IEDM) is a strong candidate for a common information exchange model in the military domain. At present is it captured using IDEF1X models. The need for an XML based version has been articulated repeatedly.

FY05: Transform the C2IEDM into three XML based versions (logical data model, physical data model, documentation) and map the IDEF1X extension rules to XML extension rules. Conduct two invited expert workshops to conduct this task and present the results to the community. Provide an exemplar C2IEDM tactical application (TOPTIVA) and examine strategies for a C2IEDM Semantic Web service.

Resources: .25 FTE faculty and one graduate student support each at ODU and NPS plus travel for participation in international MIPS meetings and workshops

2.4.5.2 XML-Based Data Engineering

Background: Data Engineering consists of Data Administration (data resources), Data Management (meaning of data), Data Alignment (target data can be obtained from source data), and Data Transformation (translate from source to data). XML supports this already (Tolk, 2004), but can be improved.

FY05: Implement a tool set to map one XML tag set (source) to the C2IEDM tag set (target) and generate and XSLT schema. Conduct two experiments: (a) populate a target data structure with source data using the XSLT schema; (b) use a web service based on C2IEDM data using source data.

Resources: .25 FTE faculty and two graduate students support at ODU

2.4.6 XMSF Distributed Testbed

Background: In FY03 and FY04, ongoing projects have supported an initial set of academic facilities for distributed proof-of-principle and technology demonstrations.

FY05 work: JFCOM is evaluating the results of this work for transition into their operations. They will not be supporting academic facilities for community access. DMSO should continue some low-level support at NPS, ODU, and GMU to provide access for emerging technologies to the M&S community, including the extension of Web services to Grid Computing (Grid services). The focus is on providing continuous availability of Web services/servers supporting broad experimentation with XMSF profiles. SAIC has committed to providing a high-performance Internet connection in order to participate.

Resources: .15 FTE faculty and 1 graduate student or technician at each institution, .15 FTE at SAIC, $60K for four server clusters to constitute a small experimental grid.

2.4.7 Standards & Liaison

2.4.7.1 SISO, IETF, OMG, Web3D/W3C, WebSim

Background: The most important process for ensuring XMSF becomes an enabler of web enabled M&S is its acceptance by the M&S community, which in turn will require broadly accepted standards. This task involves evangelizing XMSF to the M&S community and shepherding the standards process.

FY05 work: FY 05 tasking will focus on continuation of the work by the SISO XMSF Profile Study Group (SG) to develop a profile standard. There will be more focus on encouraging new adopters to experiment with XMSF technologies and the emerging profile standard, and to provide their lessons learned back to the Profile SG. Experimenters will be encouraged to submit exemplars to the testbed to support a virtual FY 05 round up demo. In addition, GMU, ODU and NPS have leadership/liaison roles to IETF, OMG and Web3D/W3C including Web3D XMSF Working Group; NPS and VMASC have leadership for WebSim, a consortium of OMG, Web3D, SISO, and OGC; and SAIC spearheads the SISO XMSF Profiles SG. OMG is of particular interest, as they recently reestablished their M&S chapter which now explicitly focuses on Model Driven Architecture (MDA) approaches to enable web based M&S and migration to web and grid services. This chapter explicitly collaborates with the Command and Control and the Homeland Security chapters of OMG.

Resources: .25 FTE for each partner.

2.4.7.2 MDA for XMSF Management

Background: The OMG MDA is mainly applied and perceived to be a pure software engineering tool. This view is too limited and does not pay the tribute to the potential use of MDA for management of heterogeneous IT environments.

FY05: ODU will show the potential of the MDA to compose simulations in a System of Systems Environment applicable to global grids, the GIG, and other service oriented environments (in articles and papers).

Resources: .25 FTE faculty support at ODU

3 CANDIDATE STANDARDS

3.1 Standards, Standards Bodies, and Liaison Assignments

Table 1 identifies key standards areas that are being investigated by the XMSF project team. The table also identifies the specific person responsible for investigating, working with, and reporting on each area as it relates to goals of the XMSF project.

Table 1. Candidate Standards and Assigned XMSF Team Members

Responsible Team Member (Standards Organization(s))	Standard(s)	Time Frame (years)
Andreas Tolk (SISO, OMG, WebSim)	MDA Meta-modeling	short (1-3) short (1-3)
Don Brutzman (Web3D, W3C, ISO)	X3D Web Services	short (1-3) short (1-3)
Mark Pullen (IETF)	XOM, SRMP	short (1-3)
Katherine Morse (SISO)	XMSF Profiles	short (1-3)
Curtis Blais (W3C)	Semantic Web	short (1-3)

In addition to these areas, Dr. Morse, SAIC, continues to maintain liaison with the DoD High Level Architecture (HLA) program and provides representation to the HLA Technical Support Team and the IEEE 1516 standards revision process as required by the XMSF project SOW.

Dr. Tolk, VMASC, encouraged the presentation to international partners, in particular NATO's M&S Group. Furthermore, the Australian SimTecT requested an XMSF workshop for 2005. The use of XMSF recommendations within the NATO MSG-027 action "Pathfinder" is currently under consideration.

3.1.1 *Model Driven Architecture and Other Meta-Modeling Standards*

This section addresses investigation into the Model Driven Architecture and other meta-modeling standards by the XMSF Partners. The material here also appears in (Tolk, 2004) presented at the 2004 Fall Simulation Interoperability Workshop (SIW).

3.1.1.1 Description

A metamodel is a precise definition of the constructs and rules needed for creating semantic models (Metamodel.com, 2004), which means implementation-specific independent descriptions of the underlying algorithmic ideas. Metamodeling has been around at least since the late 1980s, but with the advent of the Internet and business integration, process and data integration have gained importance. Metamodels are the foundation for this integration. Metamodels are very good at abstracting from lower-level details of integration and interoperability, and helping with partitioning problems into orthogonal sub-problems. The enterprise architecture components and the products of the DoD Architecture Framework (DoDAF) are actually examples for metamodels. UML in general, and specialized subsets such as the Meta-Object Facility (MOF)

and the Common Warehouse Metamodel (CWM) in particular, are languages for metamodeling. The common idea behind this is abstraction or generalization to discover common challenges and solutions. Metamodeling helps to show this common ground, to make separate communities aware that they are actually working on the same problem and, by doing so, avoiding double work and enabling reuse. Furthermore, interoperability and composability as required in (Davis and Anderson, 2003) become feasible. The use of a common methodology to express these metamodels enables the establishment of enterprise architecture hierarchies comprising composable solutions.

The Object Management Group (OMG) uses the concept of metamodels extensively (Sprinkle, et. al., 2001). Generally, metamodeling is the process of designing systems and applications through meta and meta-meta notations. The use of models and translation patterns between models ensures syntactic and semantic consistency. Four layers are defined:

- The User Object Layer contains the information to be described, which comprises the objects of the application; in other words, real classes, functions, and data being implemented.
- The Model Layer contains metadata describing the information in the User Object Layer. This model is the first abstraction layer.
- The Metamodel Layer describes and defines the structure and semantics of meta-data in the Model Layer. UML for representing processes or XML for representing data are typical metamodels.
- Finally, the Meta-Metamodel Layer contains description of the structure and semantics of meta-models.

Table 2 summarizes the layers and gives an example of each layer. Note that this architecture focuses on syntax.

Table 2. Four-Layer Metamodeling Architecture

Layer	Description	Example
Meta-Metamodel	Defines the language for specifying metamodels.	MetaClass, MetaAttribute, MetaOperation
Metamodel	Defines the language for specifying a model.	Class, Attribute, Operation, Component
Model	Defines a language to describe an information domain.	Tank, Caliber, openFire, Turret
User Objects User Data	Defines a specific information domain.	M1A1, 50, Fire, T156

It is likely that we will observe the same discussions concerning metamodels we are actually seeing in the standards domain; that is, should a metamodel be widely applicable or custom tailored to support a given domain more efficiently? As with standard solutions it is often necessary to trade domain efficiency for broader interoperability. However, we believe that more general metamodels can be used to support interoperability even between highly specialized solutions on the implementation level. In other words, while performance and domain-tailored solutions should be supported on the implementation level, broader applicability

must be the focus on the metamodel level.

Metamodels and the Model Driven Architecture. There is no generally accepted method supporting metamodeling. However, one of the most widespread approaches is the use of UML to describe metamodels. Standardized by OMG in 1997, UML has gained interest from management consulting firms, business analysts, system analysts, software developers, and programmers. It can be seen as the standard for blueprints of software solutions. Recently, however, the OMG community has taken this a step further through introduction of the Model Driven Architecture (MDA) (OMG, 2004). MDA merges the different OMG standards previously developed and used separately into a common view by applying common metamodels. The key idea of MDA is to use a common stable model, which is language-, vendor- and middleware-neutral. This is a metamodel of the concept. With such a model in the center, users having adopted the MDA gain the ability to derive code for various sub-levels. Even if the underlying infrastructure shifts over time, the metamodel remains stable and can be ported to various middleware implementations as well as platforms. To be able to do so, the MDA defines an approach that separates the specification of the system functionality (Platform Independent Model, or PIM) from the specification of the platform specific implementation (Platform Specific Model, or PSM), and the capability to transform the PIM into a PSM.

Distinguishing between needed functionality and platform specific implementation conforms to the ideas of the DoDAF; namely, distinguishing the operational architecture view and the system architecture. In addition, the mapping of DoDAF products to UML diagrams and vice versa supports the mutual application of the methods, which adds commercial expertise and support to DoDAF, and military expertise and operational relevance to UML products. DoDAF/UML has the potential to become a core model for the military PIM, a metamodel for military operations.

Another aspect of the MDA seldom mentioned is management. Similar patterns as those used to map PIM to PSM can be used to support reverse engineering. Every M&S service or component should be delivered with a PIM describing what parts of the operationally defined and required functionality is implemented. This allows gradual definition of the covered mission space based on heterogeneous and distributed components.

Metamodel Frameworks and Mappings. The metamodel for services identifies functionality to find services, to evaluate those services for applicability, to prepare and transfer input data, to invoke the service(s), to receive results, and finally to perform any necessary “clean up.” The web service stack (Figure 1) categorizes the supporting standards in a set of layers: transport, messaging, description, quality of experience, and service composition. Which standards are chosen to deliver the functionality is interchangeable and mainly driven by the overall system constraints.

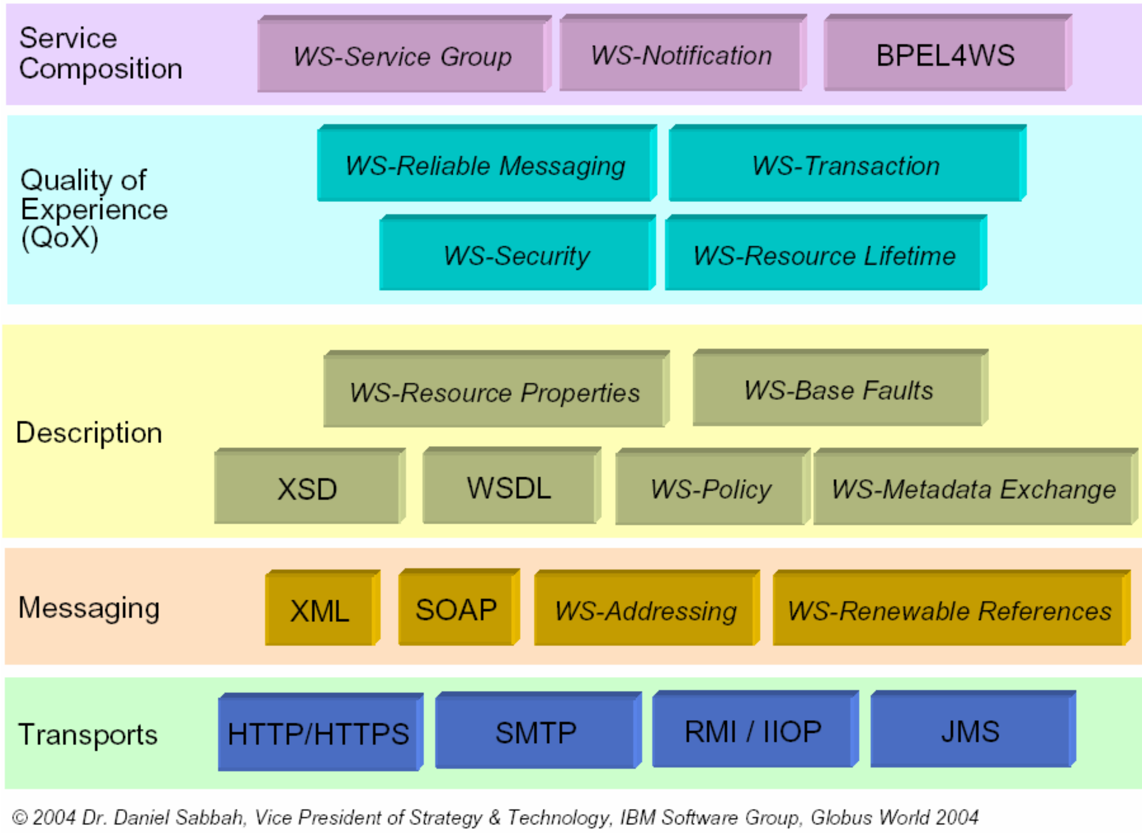

Figure 1. Web Services Stack

Generally, metamodels will help to migrate solutions (e.g., from USMTF to XML) or to adapt standardized solutions for special purposes (e.g., mapping XML based information to binary codes for a special radio link). If the idea of PIM and PSM is used, some mappings can be auto-generated based on industry standards. Furthermore, the mapping must be extended to upper levels (business processes supported) and lower levels (network protocols used) to complete the picture. An ongoing discussion is whether SEDRIS should have an XML interface in addition to the SEDRIS Transmittal Format (STF) approach. The advantage of XML is broader applicability; the advantage of STF is performance. The approach mentioned above brings both views together: the identification of SEDRIS functionality can be done using an XML description, while the coupling to make use of it can be based on STF.

The general recommendation is to layer the PIM approach and allow alternative presentations (not necessarily UML based) as alternative and completing descriptions. The resulting framework:

− is hierarchically organized in layers comparable with the International Standards Organization (ISO) Open Systems Interconnect (OSI) model,
− defines the interfaces between the layers,
− categorizes alternative standards like the web service stack is doing, and
− defines mappings between the alternative views of a solution/standard.

Using the four-layer metamodel framework described in Table 2, different syntax solutions can

be used to document the solution as well. The framework allows one to bridge the gap between special and standardized solutions as described in the second case study as well as bridging the gap between various standards. It allows one to integrate heterogeneous solutions under a common conceptual management.

This framework must be gradually filled with new ideas, such as the Base Object Model (BOM, 2004) approach currently in the SISO standardization process. Results from ongoing research, in particular (Davis and Anderson, 2003) and (Weisel, 2004), among others, must be used to improve the metamodels through definition of required metadata describing the services to avoid effects as described in (Tolk and Muguira, 2003).

3.1.1.2 Area of Applicability

Various exchangeable and complementary standards exist on the network level. On the application level, grid computing and other enabling standards are starting to play a similar role. The main challenge in service oriented architectures is not only to ensure technical interchange but also the meaningful composability of the available services to avoid unintended consequences. One of the requirements is the mapping of service functionality to supported operational ideas. The conceptual business model of the enterprise to be supported by the grid must be the guideline for the service definition. Implementation driven solutions will fall short.

Modularity, composability, interoperability, reference data models, architecture frameworks, and many other buzzwords can be heard all over M&S conferences and read in legions of papers. Unfortunately, many of these interoperability solutions are not too interoperable between each other. The communities using them are often not even aware that other communities are solving the same problems, and often solving them differently – and eventually better. The result is a rigid structure of standards solving parts of the general problem without creating the necessary bridges. A typical but not unique example is the lack of alignment of standards used for command and control (C2) and M&S support by information technology. Although the user requirements can be mapped to each other, the standards started to be aligned only recently.

The result is that we are facing an “archipelago of standardized island solutions” separated by having chosen different standards to address the same problem. Therefore, instead of having to select a solution that limits future development within a project by constraining the developers and the users too much, the XMSF Partners recommend the use of metamodels to enable effective Mapping and Migration Management.

The question for the user is what framework to choose and what methods to apply to gain the best solution under applicable constraints. It seems that after having chosen one way, many good solutions of other methods applicable to solve a problem as well cannot be applied any longer. It is hard to apply tools from one set of standards to solve problems within an alternative family, even if in principal the same conceptual problem has to be solved.

The problem is not new in the computer science world. The same challenges had to be solved when computer networks were established. The early Ethernet and Token-Ring solutions were hardly able to interconnect, the gateway from local area nets into global networks required highly qualified experts. The solution to this problem was facilitated by establishing a common

model helping to organize and map the standards and proprietary solutions of networking, the ISO/OSI model. This layered model helped to organize the applicability of solutions and enabled to identify complementary as well as alternative solutions for common problems, even if these solutions look not similar at all upon first glance.

Today, the domains needing standards are on a higher level. Grid computing makes use of the enhanced networking layers, creating a virtual computer using the interconnected components and resources. Enterprise solutions targeting the IT supported seamless exchange of knowledge within the distributed centers of an enterprise. Service oriented architectures (SOA) are seen as a key enabler to support these visions. However, in order to insure meaningful results, functionality must result from meaningful composition of services. Not every composition that is technically feasible makes sense; not everything that can be connected can work together meaningfully. Recent works on composability (Tolk and Muguira, 2003) (Weisel, 2004) (Davis and Anderson, 2003) are making this obvious, not only in the domain of M&S. All solutions currently proposed have their value and should be applied and evaluated. In addition to this "implementation driven" approach to solve the problem, conceptual work is necessary as well. The key to a common solution is the use of metamodels. We recommend starting work on a common layered metamodel to organize and map the proposed standards, very similar to the application of the ISO/OSI model for networking.

The use of commercially supported standards is mandatory for military information technology (IT) in many domains. It is therefore not only academically interesting but practical to evaluate how the challenge of complementary and alternative standard mapping and alignment is dealt with outside the Department of Defense. To this end, application of the ISO/OSI model so well known in the domain of networks and similar efforts in the emerging domain of SOA are discussed. The SOA approach uses networks that add a grid layer to the network layer to create something like a virtual supercomputer, which comprises all resources of the underlying computers, builds the grid to enable enterprise-wide computing based on distributed services implemented, and executes distributed applications in this heterogeneous IT environment. This environment not only reflects the target architecture for future parallel and distributed simulation, but also provides the IT environment for future military systems supporting Joint Command and Control (JC2); i.e., the Global Information Grid (GIG). These examples are neither complete nor exclusive. They are meant to be examples and are seen to be an initial frame for respective recommended SISO standardization and DMSO policy activities.

Using the ISO/OSI Model to Align Families of Network Standards. The ISO has created a layered model, called the OSI model (Petri, 1998) describing defined layers in a network operating system starting with physical connections and reaching up to the application level. The purpose of the layers is to provide clearly defined functions that can improve network connectivity between "computer" manufacturing companies. Each layer has a standard defined input and a standard defined output. There are legions of papers out dealing with the ISO/OSI model. Since it was developed in 1974 to standardize network communications, it was applied successfully as a theoretical framework. This is the main point stressed in this section as well: the ISO/OSI model does not deliver the actual functions; this is done by software and hardware solutions that can be mapped to this framework. In other words: the ISO/OSI model doesn't prescribe a solution but a structure for a solution, which means, it is a metamodel. The rules of

the framework describe, among other topics:

− How network devices contact each other & how devices using different languages communicate;
− How a network device knows when to transmit or not transmit data;
− How the physical network devices are arranged and connected;
− How to ensure that network transmissions are received correctly;
− How network devices maintain a consistent rate of data flow;
− How electronic data is represented on the network media.

To this end, the well-known seven layers are used to align enabling technical solutions: The Physical layer deals with issues of the data transfer medium, such as voltage used. The Data Link layer handles the data transmission rate and the necessary specifications. The Network layer deals with coding, decoding, and checking of errors and controls the flow of the packages. It is also the first layer on which “logical” connections are established. The Transport layer ensures reliability of data, e.g., by sending acknowledgements of packages. The Session layer is responsible for continuity of communication between nodes participating in a session. The Presentation layer is the first “syntax” layer, as it checks the data presentation and its correctness for the last layer. Finally, the Application layer provides the network services to the application.

The purpose of using a framework as proposed in this section is the mapping and comparison of standards. Figure 2 shows examples of standards being used alternatively and complementarily when implementing the ISO/OSI model by different manufacturers. As can be seen, the standard framework not only gives directions but also allows comparing recommendations and standards. In summary, the framework and these network standards have proven vital because they ensured that manufacturers build equipment that intercommunicates and interoperates.

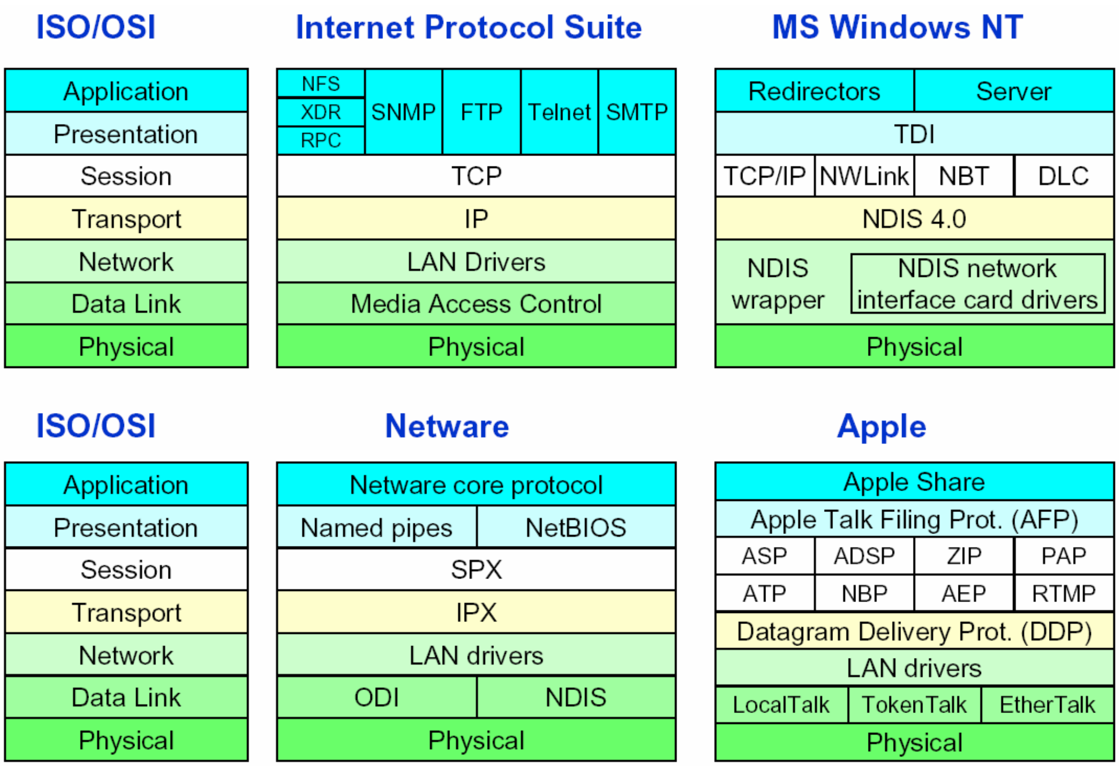

Figure 2. Multiple Implementations Conforming to the ISO/OSI Layered Model

These ideas are not limited to networks. In order to cope with the interoperability challenges facing the M&S community, the layers above the network need to be handled in the same way. What the ISO/OSI model is doing for network layers is needed on top of this for grid computing, service oriented architectures, and enterprise wide solutions as well.

Grid Computing, Service Oriented Architectures, and Enterprise Solutions. Traditionally, IT system development followed a waterfall model starting with a set of user requirements, which led through several stages to the system definition, system design, and system implementation. The reality of required distributed computing and the necessity for combining information resources using very heterogeneous IT infrastructures – different hardware, middleware, languages, etc. – can hardly be met by such traditional efforts. Starting with the ideas of net-centric operations and setting up a system of systems, the commercial world, as well as the military world, is moving from system components delivering the operationally required functionality, towards service oriented architectures. Within the commercial world, distributed computing environments operate as a uniform service, which looks after resource management and security independently of individual technology choices. Grid computing is a means of network computing that harnesses the unused processing cycles of numerous computers to solve intensive problems that are often too large for a single computer to handle. In other words, grid computing enables the virtualization of distributed computing and data resources such as processing, network bandwidth, and storage capacity, to create a single system image which grants users and applications seamless access to available IT capabilities. Just as Internet users view a unified instance of content via the Web, grid users see a single, large virtual computer. In order to access the functionality, services are defined based on common open standards. The

currently recommended way to reach this goal is the definition and implementation of SOA. Although it sounds like a collection of randomly assembled industry buzzwords, the concept is straightforward: SOA is the evolutionary development of modular development and pattern design in the era of grid computing. In other words: SOA is a collection of composable services. A service is a software component that is well defined, both from the standpoint of software and operational functionality. In addition, a service is independent, i.e., he doesn't depend on the context or state of any application that calls it.

Currently, these services are typically implemented as *web services*, with rapid evolution in progress to *grid services* – see (Morse, et. al., 2004a) for further information. The advantage of using web standards in an SOA is that the services can more easily adapt to different applications. Nothing in particular has to be done programmatically to the service, except to enable it to receive requests and transfer results using web based messaging and transportation standards. In many cases, web services are straightforward and existing software can easily be adapted to create new web services (White and Pullen, 2003) usable within an SOA.

From a technology point of view, the challenge lies in the architecture of the enterprise web services. Designing the interfaces and their relationships requires an exceptional knowledge of service technologies, the operational processes to be supported, and the technology platform underlying the services and the applications that employ them. The architect must not only understand how web services are technically constructed, he must plan their use by both existing and planned applications. If services are not constructed to be composed in a meaningful way, unintended effects within the SOA are not only possible; they are nearly unavoidable. The examples given in (Tolk and Muguira, 2003) are just some examples of such unintended consequences.

The same trend can be observed in the military world. Following the ideas of net-centric warfare (Alberts and Hayes, 2002), future military operations will be characterized by the seamless sharing of information and other resources. The technical backbone enabling this vision will be the Global Information Grid (DoD, 2002) (discussed further below). It will establish a service-oriented architecture of military services, from command and control to modeling and simulation, thus supporting the soldiers in all relevant military operations.

As stated earlier, currently web services are the favored option to implement SOA. As it is the case with networking standards, web service standards are layered and alternatives are available on the various layers, resulting in the web service stack shown below. Note that the transport layer is the connection to the network standards defined previously, standards that focus on communication and transport.

Finally, the Enterprise Architecture (EA) defines the next set of layers. Usually, EA relate to the broad procurement decisions by organizations regarding their organizational information support systems. The concept of EA has been defined and discussed variously. EA is defined by a composition of several architectures that have to be aligned in order to function correctly. (Darnton and Giacoletto, 1992) The components of the EA are:

- Strategic Capabilities Architecture: captures the strategic vision as the guiding architecture. This is the highest operational view in which to place "the pieces of the puzzle" at the right place.
- Business Architecture: devolves from this strategic capabilities architecture by grouping core competencies and necessary IT support.
- Information Architecture: maps the overall information and information exchange needs of an organization based on the strategic goal. IT itself is of a value only if it supports the strategy.
- Data Management Strategy: follows from the Information Strategy and hence the Business
- Strategy: the organization makes decisions about how data will serve its business and information needs as defined before. The result is the Data Architecture.
- System Architecture and the Computer Architecture: needed to organize the implementation of the other Architectures.

Within the EA, applications are seen as data providers and data users. Therefore, SOA are the logical next step in this hierarchy of architectures of the EA (just as the network standards can be seen as the foundations of SOA).

Note the enterprise definitions focus on semantics. There is a conceptual gap between the enterprise definitions mainly focusing on what has to be modeled and for what purpose on the one side, and the SOA and network standards focusing on the technical levels of interoperability on the other side. The Levels of Conceptual Interoperability Model (LCIM) introduced in (Tolk and Muguira, 2003) deals with resulting challenges for conceptual levels of interoperability.

Some Applicable Standards of the Military Domain. As representative standards from the military domain, we discuss the DoDAF, C2IEDM, standards for distributed simulation, and the GIG:

- DoDAF deals with the architecture of military IT systems. It must be applied to all operationally used systems.
- C2IEDM is a data model standardized by NATO, used by the participating nations of the Multilateral Interoperability Program (MIP) to exchange information describing the sphere of military operations in a manner operationally, and technically accepted based on multinational consensus.
- The actual standards for distributed simulation are Distributed Interactive Simulation (DIS) and High Level Architecture (HLA).
- The GIG is the technical backbone to enable future net centric operations.

As before, this section is neither complete nor exclusive; it just shows that standards from the various domains can and should be mapped into an according framework in order to support "the big picture."

a. The Department of Defense Architecture Framework (DoDAF). Architectures provide a mechanism for understanding and managing complexity. The purpose of the DoD Architecture Framework (DoDAF, 2003) is to improve capabilities by enabling the quick synthesis of "go-to-

war” requirements with sound investments leading to the rapid employment of improved operational capabilities, and enabling the efficient engineering of systems supporting the warfighter. The ability to compare, analyze, and integrate architectures developed by the geographical and functional, unified Commands, Military Services, and Defense Agencies from a cross-organizational perspective is critical to achieving these objectives.

In DoDAF, the three major views logically combine to specify an architecture. The described system is not limited to information technology. DoDAF has been designed to describe military systems, such as architectures that enable capabilities such as theatre ballistic missile defense. The necessary three views are the Operational View (OV), Systems View (SV), and Technical Standards View (TV):

- The Operational View is a description of the tasks and activities, operational elements, and information flows required to accomplish or support a military operation.
- The Systems View is a description, including graphics, of systems and interconnections providing for, or supporting, warfighting functions. These views potentially will close the conceptual gap between what has to be modeled and why (operational view) and how this is done (technical view).
- The Technical View is the minimal set of rules governing the arrangement, interaction, and interdependence of system parts or elements, whose purpose is to ensure that a conformant system satisfies a specified set of requirements.

In summary, the operational view is the view of the warfighter, the systems view is the view of the system designer or technical supporter, and the technical view is the set of necessary standards and alternative technical solutions enabling the composition of components of the system level to deliver the functionality needed on the operational level.

DoDAF is a tool to structure the Enterprise Architecture in the military domain. Every one of the DoDAF products will be implemented using a couple of additional standards on lower levels within the military EA. The operational views are used to model the strategic visions, the business architecture. The system views close the gap between the concepts and the IT infrastructure described by the system- and computer architecture. How DoDAF can play a valuable role to enable M&S support for capability based planning was only recently presented (Atkinson, 2004).

It is furthermore of interest that there are several approaches in progress to migrate DoDAF products to more industry supported ideas, in particular using UML diagrams to describe the products. The trend to extend UML to better describe systems has to be taken into account as well as the System Modeling Language (SysML) that is gaining visibility regarding EA modeling concepts and within the US government with respect to use in DoDAF.

It is worth mentioning that in order to support the dissemination of DoDAF products and feed several supporting tools, the way to store the information describing the products of the views was standardized by introducing the Core Architecture Data Model (CADM). The products of DoDAF describing the views are typically graphics and text first. The CADM helps to store an architecture description in a way that is interchangeable between users and tools. CADM

comprises data elements to describe a system and the architectural views as specified within the DoDAF. It is therefore a tool useful for the information architecture. However, CADM specifies that data have to be exchanged between components and which standards have to be used, but it is not a data model to exchange data in the operational level (which is part of the system or computer architecture – or even lower). This is done by operational/tactical data models as used by tactical systems.

In summary, the enterprise aspects of strategic goals and business models to be supported are reflected in the operational views of DoDAF, Information and Data Architecture are the base for the system views, and the applied standards have to be captured in technical views. DoDAF and the use of commercially supported enterprise architecture description methods are no longer mutually exclusive, but the trend is towards the approaches being merged and mutually supportive.

b. Command and Control Information Exchange Data Model (C2IEDM). As many interoperability challenges cope with the coupling of legacy systems via predefined interfaces, one area of particular interest is standardized data exchange between such components. Due to various reasons ranging from intellectual property protection to the use of undocumented legacy code, components are often treated as black boxes. Furthermore, static systems focusing on data storage and representation have no need for behavioral descriptions, as there is no behavior modeled within them. A main portion to gain a high level of interoperability between such systems is contributed by standardized data elements used for information exchange between such systems, often referred to as a common language or a common ontology. The limits of this approach have been shown in (Tolk and Muguira, 2003) and will not be repeated here.

The real potential of SOA lies in the possibility to compose services and to orchestrate their execution enabling new functionality compositions to fulfill the current often changing user requests “on the fly.” Many users perceived the resulting challenge of interoperable data exchange between such services to be solved by using XML. However, although the application of the XML enabled a new level of interoperability for heterogeneous IT systems, it doesn’t ensure that data exchanged is interpreted correctly by the receiving system. This motivates data management to support unambiguous definition of data elements for information exchange. Using a common reference model improves this process leading to "model based data management (MBDM)" as introduced to SISO in (Tolk, 2004b) and technically detailed in (Tolk, 2004c). The main idea is to use a common reference data model to unambiguously define the data to be exchanged; namely, C2IEDM.

C2IEDM is the data model used within the Multilateral Interoperability Program (MIP) for data exchange between operational systems as well as for data management of information exchange requirements between national C2 systems. Model documentation is available on the program website (MIP, 2004) and comprises definitions for all data elements of C2IEDM, all relations, as well as explanations and background information. Besides the technical maturity of this data model, the choice of C2IEDM as the core model for military MBDM was driven by the fact that all participating MIP nations agreed that the information exchange captured in C2IEDM is operationally relevant and sufficient for allied operations. In other words: military and technical experts from 10 full member nations (Canada, Denmark, France, Germany, Italy, The

Netherlands, Norway, Spain, United Kingdom, and United States) as well as 14 associate member nations agreed that C2IEDM is an adequate and operational meaningful way to exchange information about military operations, including new tasks like anti-terror operations. C2IEDM covers 176 information categories including over 1,500 individual content elements (MIP Block I, see (MIP, 2004) for details).

Technically, C2IEDM utilizes the concepts of categories and subcategories to model existing information exchange requests, such as orders and reports, in military operations and a set of rules allowing for extension of the model without having to modify the existing kernel. Furthermore, C2IEDM distinguishes between the generic hub, which is internationally standardized by NATO in form of an Allied Data Publication and the sub-functional areas comprising additions and refinements being of national concern. Although the focus of C2IEDM is information exchange, some national command and control systems (among others Canada, Italy, and The Netherlands) not only use the C2IEDM as an interface but use it as a tactical data model as well. Finally, it is worth mentioning that several organizations are working on XML versions of the C2IEDM.

In summary, the concept of SOA requires a common understanding of the data to be exchanged between the services. If the services are using different data models internally, a mapping between the data models is necessary. In trivial cases, some of this mapping can be done automatically, e.g., mapping the data elements “First Name” and “Last Name” of one model to the data element “Customer Name” in another model. A good overview of applicable methods for automatic mapping of XML data is given in (Su, et. al., 2001).

However, the author is convinced that to cope with the challenge in general, data engineering as defined in (Tolk, 2004b) is needed. It is not so important which data model is used for MBDM, it is more important that an unambiguously defined data model is used as a reference. The methods of federated database development as introduced in (Sheth and Larson, 1990) or XML derivates of it can always be used to map this data model onto each other, if they cover the same information space.

Note that tactical data models, such as the C2IEDM or the Joint Common Database (JCDB) or the database of the Future Combat Systems (FCS), have to capture and structure the information that has to be exchanged on the battlefield with other participating systems. This is a completely different purpose and hence a different level in the enterprise architecture hierarchy than the CADM described previously. The role of the CADM is to enable the exchange of information about the architecture of the systems, not operational data. In this sense, the tactical data models such as C2IEDM are “just a technical view” in the CADM; in other words, CADM and C2IEDM are both applicable at the same time on different levels of the enterprise architecture to be supported.

c. Standards for Distributed Simulation. In one sense, M&S is an IT service to support the warfighter. When M&S services have to reach the warfighter using operational systems, the standards discussed in this document have to be applied. If M&S services are used in the operational context, they have to follow the same rules and constraints as other Joint Command and Control services. The same ideas of interchangeable alternative implementations in various

layers with well-defined interfaces embedded in a common conceptual (business) model are applicable for M&S solutions; therefore, they must be of interest to the SISO community as a whole, even without having their operational use in mind.

Currently, the two dominant standards for military distributed simulation systems are the Distributed Interactive Simulation (DIS, 1995) protocol and the High Level Architecture (HLA, 2000). (Atkinson, 2004) showed not only that M&S needs to support the DoDAF, but also provided examples and references on how the DoDAF can be used to support M&S. Another example of the connectivity of DoDAF products and M&S applications is given in (Wittman, et. al., 2003), where the DoDAF products are used to capture the operational view to be supported by the M&S functionality. This shows how M&S is embedded into the military EA on all levels. Furthermore, (White and Pullen, 2003) showed how M&S components can be migrated towards web-based solutions. Their results are generalized in this section dealing with the migration of M&S solutions based on the HLA or the DIS standard to become applicable as M&S services in SOA environments.

Both standards, DIS and HLA, treat simulation systems as black boxes. This is especially the case for DIS, which generates Protocol Data Units (PDU) as a data source and consumes them as a data sink. There is, however, no interface mechanism to orchestrate the system and there is no way to describe the behavior. An M&S component being DIS enabled is therefore easy to integrate into a SOA: the only thing to do is to change the PDU interface to an XML interface (XML descriptions for PDU are easy to program) and the DIS interface with a web service interface (which can be done automatically). It may even be easier to simply wrap the component and translate the protocols within the wrapping layer.

In principle, the same is true for HLA; however, the interface is more complicated due to the specification of the Runtime Infrastructure (RTI). However, that this functionality can be mapped to other middleware solutions, such as using Common Object Request Broker Architecture (CORBA) specifications to emulate the RTI functionality, has already been shown several times. The general mapping can be done using MDA. This is already commercially supported by new solutions, such as by the Integrated Development Environment (IDE) SIMplicity (Parr and Keith-Magee, 2003): At the user interface level, SIMplicity presents the developer with a modeling environment to specify the Platform Independent and Platform Specific models for their simulation, applying UML notation wherever applicable. The modeling process supports the developer through the design, implementation, and execution phases of the simulation development life cycle. From the model, a code generation engine is employed to automatically create all the integration and component stub-code required to support the simulation design on the targeted Platform Specific middleware. M&S components can be derived for various platforms and middleware solutions, such as the various RTI derivatives 1.3 NG or IEEE 1516, or the generation of a necessary DIS protocol access layer.

In summary, the current M&S standards can not only be mapped to each other, but methods as described in (White and Pullen, 2003) and (Parr and Keith-Magee, 20003) can help to make them available in the form of operationally applicable M&S web services within an enterprise architecture.

d. Global Information Grid (GIG). Following the ideas of net-centric warfare (Alberts and Hayes, 2002), future military operations will be characterized by the seamless sharing of information and other resources. The technical backbone enabling this vision will be the Global Information Grid (DoD, 2002), which will be implemented using the Internet Protocol version 6 as the technical baseline. It will establish a SOA of military services, from command and control to modeling and simulation, supporting the soldiers in all relevant military operations. The GIG will merge the ideas such as described in this section and will make them applicable to support the warfighter in all his tasks.

Even more challenging than the technical aspects of GIG will be the organizational ones. As the GIG will be a common information exchange hub, the IT backbone for military IT support, the business cases of the DoD have to change from pipe to hub structures. Information should and will be made available to every user in need on his request and not by decision of the data producer. The ideas are described in (Alberts and Hayes, 2002).

The organizing principle is the establishment of communities of interest (COI). While the Defense Information Systems Agency (DISA) will deliver a set of enterprise wide applicable core services in the form of the Net Centric Enterprise Services (NCES) or GIG Enterprise Services (GES), the user communities will be responsible for their own namespace and process management. The methods described in this document will help avoiding unintended behavior within this military SOA when composing services, in particular when more than one COI are involved.

Some salient points regarding an M&S COI for the GIG:

- The M&S COI for the GIG is now in the process of formation
  - High-level DMSO-DISA agreement
  - Namespace is critical to effective XMSF deployment
- Opportunity to create effective C4I-Simulation links in Horizontal Fusion (HF)
  - ASD(NII) program to demonstrate breaking down stovepipes
  - Annual "graduation exercise" in August displays C4I best-of-breed Web services
- Opportunity to show effectiveness of M&S Web services
  - XMSF HF goals:
    - August 04: provide context for HF using simulation such as JFCOM's Joint Urban Operations with an early XC2I prototype
    - August 05: operate XBML and XC2I using real C4I system feeds
  - Effects long term community objective
- Integrated C4I environment with simulation tools supporting military operations

e. Military Mission and Means Framework. Another topic is the Military Mission and Means framework (MMF) (Sheehan, et. al., 2003), which may complement DoDAF products in a way directly applicable to the M&S domain. Analyses of the MMF by the Joint Staff as well as DoDAF developers showed that DoDAF and MMF are not only overlapping views to be supported by underlying implementation levels, including simulation and Command and Control operations, but can be used to mutually support each other. It can be said that the operational view of DoDAF is dealing with the missions and the systems view with the means (using the standards defined in the technical view to exchange information). The domain of executable

architectures, as currently discussed for the Joint National Training Capability (JNTC), is also affected by the proposed standards. Only recently, ODU/VMASC participated in a workshop of experts in executable architectures sponsored jointly by Assistant Sec of Defense for NII and Deputy Dir, Technology, DMSO. The established working group will develop a coordinated approach for addressing the technical obstacles to executing architectures, establish coordination process for technology development across Services and OSD, and contribute to the revision of DoDAF. Based on Army Training Support Center (ATSC)/VMASC Training Support System (TSS) modeling and Enterprise Architecture Framework initiatives, Co-Chairs were very interested in exploring how the TSS could fit into future DoD executable architecture development, especially the integration of training support enterprise modeling with emerging DoDAF architecture modeling and simulation tools. A program plan for the working group is being developed with potential of identifying the TSS as a pilot executable architecture testbed for the DoD initiative. Discussions continue between VMASC and ATSC to explore the proposal and potential impact (TRADOC, 2004). First results concerning an executable DoDAF are given in (Dryer and Berbesi, 2004). One impact is that the CADM must comprise the data elements needed for an executable architecture. Note that this may include in special studies the use of C2IEDM to exchange information between systems when simulating the systems view.

3.1.1.3 Maturity

Many of the standards and practices are well established at this point, although the development community continues to rapidly evolve. A clear road map is needed to help the community through the vast array of standards and technology initiatives and to set a foundation for future interoperability and reuse.

3.1.1.4 Required Changes

In the previous sections, an exemplary selection of standards dealing with the broad aspect of interoperability for components of the IT support for warfighters has been given. However, already this small selection showed the variety of alternative solutions, some of them exclusive, others complementary or real alternatives. In other words: choosing the right family of standards early is currently crucial for interoperability success. As discussed, technical standards alone are not sufficient to reach meaningful interoperable solutions. The technical solutions must be embedded into common concepts applicable to all components of the enterprise architecture. Strategic objectives and the business rules must be aligned and harmonized. To this end, the commercial world through new approaches such as grid computing and service oriented architectures and the military world through its growing attention to the GIG and GES need metamodels to manage the alternative solutions. Metamodeling is precisely defining constructs and rules needed for creating semantic models. It enables transparency of the model and its assumptions and constraints necessary for composable services without forcing open-source solutions, hence protecting intellectual property. Mapping transforms two models in an unambiguous way into each other through defined mediation rules. Although no general solution has emerged so far, the use of UML for modeling on all levels is becoming a de facto standard. Such metamodels can be used to map and merge existing standard solutions of the commercial and the military domain, including networking standards, web service, SOA, DoDAF, NCES and GES. SISO can and should play a role in setting up this framework to actively push M&S standardization efforts into related domain and respectively use their

solutions to support SISO efforts. XMSF partners are working directly with and through SISO to rapidly introduce metamodeling concepts and techniques to the M&S community.

3.1.1.5 Timetable for Adoption of Changes

There are numerous initiatives already in progress across DoD indicating that the concepts, though not broadly understood, are already being accepted and actively promoted. Policy changes to help guide the community are needed in the near term (2005-2006).

3.1.2 Extensible 3D Graphics

3.1.2.1 Description

X3D is a powerful and extensible open file format standard for 3D visual effects, behavioral modelling and interaction. It provides an XML-encoded scene graph and a language-neutral Scene Authoring Interface (SAI). The XML encoding enables 3D to be incorporated into web services architectures and distributed environments, and facilitates moving 3D data across applications. The SAI allows real time 3D content and controls to be easily integrated into a broad range of web and non-web applications.

3.1.2.2 Area of Applicability

X3D replaces the hodgepodge of incompatible products with an interchange format that can translate products into shared scenes for web interoperability.

3.1.2.3 Maturity

The primary X3D specification has been approved by ISO as an International Standard. Supporting X3D specifications for XML, Classic VRML, Compressed Binary encodings and for ECMAScript/Java language bindings are now in final review, with approval likely in April 2005. X3D has been approved for Navy-wide use by the Department of the Navy Chief Information Officer (DON CIO) Business Standards Council. An open source reference implementation is available for use and numerous companies have released products conformant to the X3D specification, with others in development.

3.1.2.4 Required Changes

DMSO failure over the 2002-2004 timeframe to provide open-source licensing terms for SEDRIS software means that Web3D developers are pursuing alternate codebases to achieve similar/identical functionality. SEDRIS has been unresponsive to multiple requests to pursue XML bindings to enable web services compatibility and interoperability.

A just-completed X3D Technical Summit members-only event listed about three dozen technical imperatives for 2005.

Just as the Navy has taken the step to approve X3D as a unifying approach for visualization, the same decision needs to be made by DMSO for the DoD M&S community.

3.1.2.5 Timetable for Adoption of Changes

The X3D standard is in an annual ISO-standard update cycle. The Web3D Consortium is currently accepting comments on Amendment 1 to the X3D abstract specification, ISO/IEC 19775, including: Computer-Aided Design (CAD) Geometry component; CAD Interchange profile; Programmable Shaders component; 3D Texturing component; and Cubic Environment Texturing component. Promulgation of X3D as a standard for DoD M&S use can begin now.

3.1.3 Web Services

3.1.3.1 Description

A Web services is "a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format (specifically WSDL). Other systems interact with the Web service in a manner prescribed by its description using SOAP messages, typically conveyed using HTTP with an XML serialization in conjunction with other Web-related standards." (W3C, 2004a) Web services are being supported and adopted by industry as a way to securely integrate heterogeneous applications over the Internet (Ferguson, et. al., 2004). As such, it is a primary strategy in XMSF as described in (Brutzman, et. al., 2002) (Brutzman and Tolk, 2003) (Pullen, et. al., 2004). From (Barry, 2003):

> [Web services and service-oriented architectures] …are going to fundamentally change the way we build our internal systems – the information systems that support our organizations – and how our internal systems interact with external systems… We are on the cusp of building "plug-compatible" software components that will reduce the costs of our software systems at the same time increasing the capabilities of the systems. A service-oriented architecture is essentially a collection of services. Connections among services are Web services. A service is a function that is well-defined, self-contained and does not depend on the context or state of other services.

A Web services stack was shown in Figure 1 earlier. Fundamentally, the stack consists of:
- Transport ; e.g., communications protocols such as HTTP, SMTP, FTP, etc.
- Messaging; e.g., using SOAP (W3C, 2003)
- Description; e.g., using WSDL (W3C, 2001)
- Quality of Experience;
- Service Composition; e.g., various processes for discovery, such as UDDI (OASIS, 2004), for aggregation through Business Process Execution Language for Web Services (BPEL4WS) (IBM 2003), and for choreography (W3C, 2004b).

As discussed earlier, these are building blocks for the GIG SOA. Application of such techniques clearly apply to a characterization of XMSF applications, while applying much more broadly as well.

3.1.3.2 Area of Applicability

The fundamental area of applicability is the GIG. The formation of the M&S COI within the GIG indicates recognition that future warfighting systems, including M&S systems, will be composed from services enabled by the emerging and evolving standards. Through 2004, many

XMSF technical efforts, multiple projects, and capstone demonstrations at I/ITSEC provided examples and initial capabilities to help inform the M&S community in the application of these technologies across a broad front – refer to Section 5 of this document for more detail on the Experimentation Command and Control Interface (XC2I) exemplar.

The intention is to develop and text such exemplars in operational environments, laboratory environments, or under the auspices of standards organizations such as Web3D before submitting proposals to relevant standards bodies. Some specific areas of exploration are DIS-XML (working group launched in Web3D in January 2005) targeted to SISO and IEEE, XOM targeted for IETF, and XML Schema-based Binary Compression (XSBC) for the W3C Binary Characterization Working Group.

NPS held a restart meeting for the Web3D Consortium DIS working group, on 11-12 January 2005 in Monterey, with teleconference access provided. All participants are enthusiastic about establishing this working group and getting some powerful work done together. Meeting minutes are provided below to illustrate the activities expected to occur along various fronts.

Meeting participants: Alan Hudson, Yumetech; David Maynard, L3; Don McGregor, NPS; Mark Pullen, GMU; Don Brutzman, NPS

Strategic objective for DIS-XML working group: How can X3D and DIS open up the modeling & simulation (M&S) market to open-standards Web-based technologies.

Goals:

- Explore & demonstrate viability of DIS, DIS-XML networking support for X3D
  - Workability, interoperability of IEEE DIS protocol with other web systems
  - Suitability and usage for Web Services
  - Wide-area networking using XMSF Cross-network Overlay Multicast (XOM)
  - Streamability of XML-based behavior information for X3D
- Continued development of DIS-related open-source codebases
  - DIS-XML schema
  - DIS-XML autogenerated Java codebase
  - DIS-Java-VRML maintenance
  - XOM codebase, testing and establishing multicast simulation channels
  - Utilities: packet recording/playback, compressed archiving
  - Compression comparisons using XML Schema-based Binary Compression (XSBC)
- Addition of DIS-specific node(s) to X3D
  - Maintenance and extension of the DIS component for X3D Specification
  - DISEntityManager, DISEntityTypeMapping for new-entity discovery/display
  - Suitability of other existing DIS Protocol Data Units (PDUs) to X3D
  - Best practices for applying DIS to X3D Geospatial scenes
- Standardization collaborations
  - Web3D: X3D Specification amendments
  - SISO: IEEE DIS Specification
  - IETF: overlay multicast standardization

Who is interested, and why:

- George Mason University (GMU): XMSF, XOM
- Link team of L3 Communications: DIS, DIS-XML, XOM, X3D
- Old Dominion University (ODU): DIS, X3D
- Media Machines: X3D DIS component implemented in C++
- Naval Undersea Warfare Center (NUWC): participate in wide-area simulations
- NPS MOVES Institute: XMSF, X3D, XSBC, DIS, DIS-XML, XOM, wide-area sims
- Planet9: X3D, wide-area simulations
- Yumetech: Xj3D browser, XMSF, X3D, XSBC

Working group charter refresh:

- Group mechanics:
  - email lists: dis-xml@web3D.org (members) and xmsf-announce@MovesInstitute.org
  - website: http://www.web3d.org/_tbd_ (both public and member-only)
  - cvs site: http://sourceforge.net/projects/xmsf
  - XMSF bugtracker: DIS-XML component available
    http://xchat.movesinstitute.org/bugzilla
  - meet every other week via teleconference
  - use GMU's NEW multimedia conferencing to test networking, audio/video
    http://netlab.gmu.edu/NEW
- Access
  - Web3D members only, under new membership agreement
  - All submissions under Intellectual Property Rights (IPR) and predeclared available for standardization as Royalty Free (RF) use
  - Meeting plans: Web3D Symposium, SIGGRAPH, XMSF deep dives, SIW, etc.
  - L3 may be able to host a f2f meeting (Orlando FL or Arlington TX)

NPS presentations:

- status of existing dis-java-vrml and dis-java codebases
- recent progress establishing dis-xml codebase, which includes DIS packets mapped to/from XML
- how to retrieve codebases from SourceForge via CVS
- use of DIS in Rick Goldberg's DISKIT package in the
- Simkit/Viskit Discrete Event Simulation (DES) application
  http://www.movesinstitute.org/xmsf/xmsf.html#Projects-WCM

Yumetech presentations:

- DIS component support in Xj3D
- proposed new nodes: DISEntityManager and DISEntityTypeMapping will discover new entities from network traffic and display corresponding entity geometry from announced X3D url(s)
- Picking sensors for object-to-object collision detection inside X3D, line-of-sight (LOS) detection, virtual sensors, terrain following, etc.

L3 Link presentation:

- recent I/ITSEC demonstrations: will distribute slideset once DIS-XML mailing list established

- lessons learned and recommendations using dis-java and alpha dis-xml code
- considering what areas to work on

Work list, near term:

- Revised charter: Don Brutzman
- Website revamp: Don Brutzman
- DIS-XML release: Don McGregor
- XOM release: Mark Pullen & Denny Moen GMU, Don McGregor
- Sourceforge fixups: Don McGregor
- Mimi Nguyen ODU provided DIS-Java classes for PduSniffer and DIS electronic emissions PDUs, need to be integrated in codebases
  - DIS-Java build: Alan Hudson
  - DIS-XML build: Don McGregor
- Demonstrate DIS X3D viability with GeoSpatial profile scenes
  - Xj3D, DIS-Java: Alan Hudson, Don McGregor (maybe in AUV Workbench)
- Comments on X3D specification (plus Amendment 1 & Amd 2 proposals) for simulation needs: David Maynard
- Meeting/tutorial at Web3D 2005 Symposium, 29 March - 1 April 2005, Bangor, Wales, United Kingdom (UK) - Don Brutzman http://www.hpv.informatics.bangor.ac.uk/s2005

Future-work issues for discussion:

- Support for various coordinate systems
- How to apply DIS to Web Services?
- X3D Specification Amendment 2 plans
- Relationship to SISO DIS recharter effort
- DIS-lite and DIS-plus development;
  - addition of H-Anim gesture PDUs or HAnimStreaming node
  - general XSBC streaming of X3D behaviors, etc.

References:

DIS component of X3D specification
http://www.web3d.org/x3d/specifications/ISO-IEC-19775-IS-X3DAbstractSpecification/Part01/components/dis.html

DIS-Java-VRML working group site and code distribution
http://web.nps.navy.mil/~brutzman/vrtp/dis-java-vrml

Sourceforge site: XSBC (and XOM in February 2005)
http://sourceforge.net/projects/xmsf

Yumetech Xj3D extensions for DIS and picking
http://www.xj3d.org/extensions/DIS.html
http://www.xj3d.org/extensions/DIS_examples.html
http://www.xj3d.org/extensions/picking.html
http://www.xj3d.org/extensions/picking_examples.html

3.1.3.3 Maturity

Standards for Web services are both rapidly becoming established and rapidly evolving as the commercial world invests enormous sums of money into this approach to building IT solutions. The DoD has opportunity to participate in the standards organizations to influence how these evolve while also creating strategy for their adoption and employment.

3.1.3.4 Required Changes

The M&S community needs to continue to work with the emerging GIG concept to ensure wide-scale interoperability with C4I systems as well as with other simulation systems. One of the key areas for research is extension of Web services capabilities to accommodate data streaming.

3.1.3.5 Timetable for Adoption of Changes

Exploration and drafting of applicable standards will continue through FY05 and the early part of FY06. Target date for submission of proposals to relevant standards bodies is mid-FY06. Expected approval is late FY06 to early FY07.

3.1.4 XMSF Profiles

3.1.4.1 Description

To create practical understanding of the application of XMSF precepts to real products, SISO established an XMSF Profiles Study Group in September 2003. The Study Group is working to determine the required scope for XMSF Profiles and to define their structure and application. The Study Group Terms of Reference (TOR) document (Morse, 2003) states that the specification of XMSF will be in the form of a collection of profiles detailing *how to interoperate* with XMSF compliant systems. XMSF Profiles SG progress was presented to the M&S community at the Fall 2004 Simulation Interoperability Workshop.

The SISO XMSF Profiles Study Group is actively defining formal technical specifications for application of interoperable Web-based technologies enabling composable and reusable M&S elements, and facilitating enterprise integration. XMSF profiles will enable inter- and intra-domain interoperability. The Study Group has established that at a macro level a profile will consist of:

- Applicable Web technologies and protocol standards
- Applicable data and metadata standards, including a tailoring of the set of selected standards (e.g., tailoring of authentication standards)
- Recommendations and guidelines for implementation
    - Composability guidelines
    - Technology application guidance
    - Hardware configuration recommendations, requirements, and constraints; e.g., network bandwidth, minimum processing capability
    - Software configuration recommendations, requirements, and constraints; e.g., browser support for specific applications
    - Specialization of design methodologies

Furthermore, the Study Group has established the following objectives for XMSF Profiles:

- Provide unambiguous specification of the interfaces and functionality of components of the framework.
- Ensure interoperability between existing and new Web-enabled technologies, both within M&S and in related domains.
- Provide the necessary metadata to facilitate composability and reuse of components across multiple M&S application domains.
- Facilitate development of new applications and services that are functionally interchangeable with existing applications and services.
- Enable development of new applications and services that readily extend functionality for continuous evolution of capabilities.

As background research, the group has examined the use of profiles in other areas, such as several of the defined or emerging ISO standards and Web-based technologies, including X3D (Extensible 3D Graphics), XHTML (Extensible HTML), SMIL (Synchronized Multimedia Integration Language), XHTML+SMIL, Cascading Style Sheets Level 2 for mobile devices, Scaleable Vector Graphics (SVG), XHTML + MathML + SVG, WebCGM (Computer Graphics Metafile) and others.

The Study Group is currently preparing a Concept of Operations (ConOps) describing how each XMSF stakeholder develops, finds, and uses profiles. Stakeholders include the following (with brief description of their roles):

- Simulation/system users
  - Provide feedback on usefulness and ease of use of simulation/system (developed in accordance with profile(s))
  - Identify new simulation/system requirements
- Simulation/system developers
  - Develop/integrate new simulations/systems consistent with existing profiles
  - Identify compositions of profiles
  - Identify the need for new profiles
  - Develop/integrate new simulations/systems without an existing profile
  - Develop profiles for new simulations/systems
  - Provide feedback to Profile Community/Working Group on effectiveness of profile standard
  - Provide feedback to Profile Certifying Authority on accuracy of individual profiles
- Profile Community/Working Group
  - Develop profile standard
  - Update profile standard based on experience of simulation/system developers
  - Make recommendations to Profile Certifying Authority about certification processes and metrics
- Profile Certifying Authority
  - Maintain repository and CM of approved profiles
  - Develop certification processes and metrics
  - Ensure accuracy and consistency of the profile standard as it evolves
  - Assess individual profiles according to the profile standard, and certification processes and metrics, with a possible profile V&V role to ensure that profiles remain consistent

with the profile standard if/when it changes

- Profile Managers - advocate for profiles within a domain
  - Negotiate alignment of profiles where there is a mismatch of nomenclature or functional overlap
    - Identify alternative implementations of capabilities
    - Identify aggregate related dependencies
  - Identify missing capabilities
  - Recommend foundations and enhancements to the profile standard based on user needs
    - Identify existing domain standards
    - Migrate domain standards into profile
- Implementation Certification Agents
  - Certify that a capability implementation is consistent with a profile
- Customer - e.g.. SPOs and Program Managers
  - Specify the requirement to adhere to specific profiles

Figure 3 provides an overview of role relationships across these stakeholders.

This effort is helping Study Group participants come to grips with the nature and purpose of XMSF Profiles. To further inform the activity of the group, specific exemplars are needed – much can be learned by trying to describe the profile for a particular application, even before the Study Group has fully defined how profiles should be specified.

3.1.4.2 Area of Applicability

No guidelines currently exist for application of XMSF concepts to M&S system development and interoperability. The XMSF Profiles, when established, will provide this guidance to the M&S community.

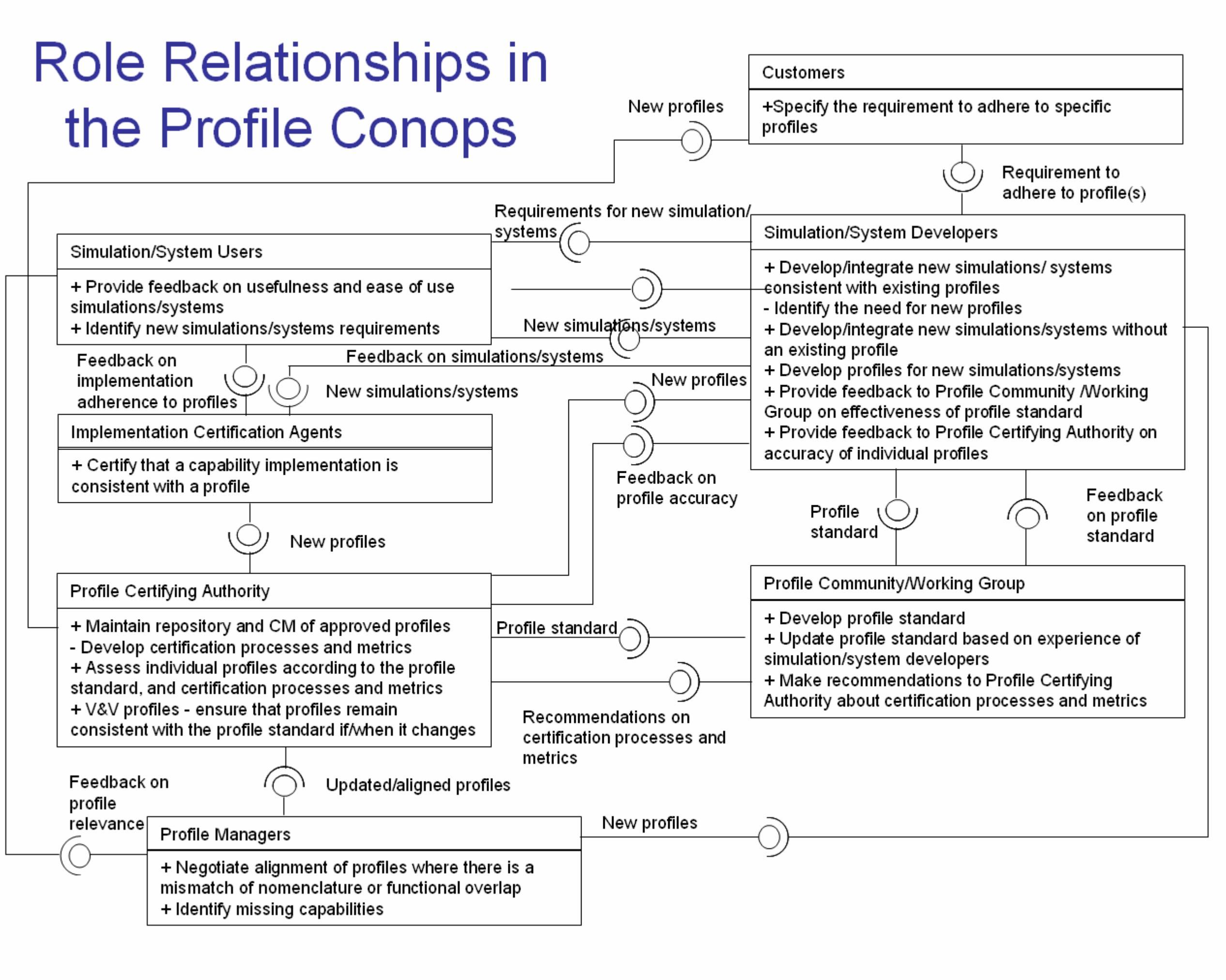

Figure 3. Stakeholders and Role Relationships from the XMSF Profiles Concept of Operations

The XMSF team has attempted to identify many of the core Web technologies that are established and emerging, and attempted to create a basis for profiling the characteristics of particular applications. (Blais, 2004) addressed part of the definition of XMSF profiles; namely, that a profile consists of: (1) applicable Web technologies and protocol standards and (2) applicable data and metadata standards. The paper explored a profiling approach that identifies (1) an *Interoperability Profile*, taken as the level of interoperability according to the LCIM (Tolk, 2004a); (2) an *Implementation Profile* from identification of Web technologies from the Semantic Web Services Stack (see, for example, (Obrst, 2003)); and (3) a *Security Profile* from identification of security implementation standards from the Web Services Security Stack (see, for example, (IBM, 2002)). These notions were applied to two analytical combat modeling projects to try to characterize their current implementation as well as work in progress to incorporate additional or expanded Web technologies.

Association of profiles with actual applications helps to distinguish features of the applications that support greater levels of interoperability, providing both an appraisal of what an application can do now and an assessment of how it can be modified to achieve higher levels of

interoperability in the future, as may be required.

For profiles to successfully enable interoperability their initial content and structure must be agreed upon. As the underlying technologies and standards evolve the profiles and their implementations will need to be upgraded in an iterative fashion to maintain interoperability. Knowing what those technologies are and how they interrelate facilitates co-evolution of the applications as underlying technologies evolve.

Of particular interest is the possibility to use XMSF profiles to define M&S profiles for the Global Information Grid. In collaboration with the Army's Battle Command, Simulation and Experimentation Directorate (BCSE, former AMSO), an initial analysis was conducted which will be published in a workshop paper during the Spring 2005 Simulation Interoperability Workshop in San Diego, CA.

3.1.4.3 Maturity

The XMSF Profiles work is proceeding in accordance with the plan from the SG TOR. Numerous exemplar products have been developed and demonstrated to help guide the community and provide a basis for definition of profiles by the SG.

3.1.4.4 Required Changes

Next steps for the SG include determining what to use to represent/describe/convey XMSF profiles. Some considerations:

- Need to determine both content and structure/format
- Contents of profiles must support the profile definition
- Contents of profiles must support the roles of the stakeholders
- Since unambiguous interpretation is our first objective, focus on technologies that support automated methods
  - Searching
  - Composability
  - Integration

The work is leading to refinement of technical requirements to be met through the profiles:

- Provide unambiguous specification of the functionality of components, and interfaces among components of the framework
  - WSDL
  - Use formal specification technologies
    - UML
    - DoDAF
- Ensure interoperability between existing and new web enabled technologies, both within M&S and in related domains
  - Define XML schema for tagging standards (protocol, data, metadata) and other profiles
    - References to Reference FOMs and BOMs
    - References to established metadata standards (namespace)
  - Identify other interoperability technologies and standards
    - HLA

    - Defense Information Standards Repository (DISR) replaces the JTA
    - SIP (RFC 3261)
- Provide the necessary metadata to facilitate composability and reuse of components across multiple M&S application domains
  - Work with appropriate DoD namespace managers
  - Should we define our own metadata tags to support searching?
    - As extensions to WSDL to support searching?
    - For HLA-compliant simulations, should we try to codify federation agreements?
    - See recommendations of data/metadata subgroup of CMSE workshop, Simulation Interoperability Workshop paper 04S-SIW-050, and the RAND report
    - Business Process Execution Language for Web Services (BPEL4WS)
- Facilitate development of new applications and services that are functionally interchangeable with existing applications and services
  - WSDL
- Enable development of new applications and services that readily extend functionality for continuous evolution of capabilities
  - Possible use of Resource Description Framework (RDF) and/or Web Ontology Language (OWL) to describe semantics

3.1.4.5 Timetable for Adoption of Changes

Adoption will require an extended process of community building and standards definition. A timeline for XMSF Profiles standardization is:

- FY05 – complete initial profile definitions and example instances
- FY06 – SISO draft completed
- FY07 – draft accepted in SISO

3.1.5 XMSF Overlay Multicast and Internet Community Standards

3.1.5.1 Description

The ability to perform many-to-many multicast over an open network is very important to the real-time distributed virtual simulation (RT-DVS) community and key to implementing XMSF. Implementing end system or overlay multicast for real-time distributed simulations allows the continued use of open protocols as implemented across the Internet. As a result, RT-DVS is no longer dependent on consistency of network policy implementation across the Internet, Global Information Grid, etc. and supports the RT-DVS community's effort to move to Web based technologies.

Distributed virtual simulations operating across a network in human time generate large amounts of message traffic among the computers hosting the simulation applications. Efficient distribution of this traffic requires many-to-many communications in a dynamic group environment because unicast transmission among N computers in the group requires $O(N^2)$ total message transmissions, where multicast requires only O(N) (Simon, et. al., 2003). In addition, this simulation environment may not necessarily be homogenous, e.g. each simulator is likely to be different although they dynamically share common simulation objects over time. The result is that simulation objects may have membership in multiple groups with each group's membership

changing at different rates.

Distributed virtual simulations also require specific delay bounds to support the delivery of real-time, interactive visual and audio information at human response times. This environment can be described as a multiparty collaborative environment running multimedia applications. The underlying networking environment needs to support a large number of participants dynamically joining and leaving the applications across the myriad of public and private networks that make up the Internet. Because each of these networks is independently managed, the RT-DVS applications cannot rely on the Internet to deliver the necessary QoS even where QoS mechanisms are deployed. As a result, networking real-time simulators together has seen deployment only in specialized local area networks or on private networks dedicated to the simulation environment. The problem can be overcome by an overlay multicast protocol supporting efficient, reliable multicast transmissions over existing network protocols such as UDP/IP. This allows for cross-network operation: distribution across multiple network administrative domains found in the Internet.

3.1.5.2 Area of Applicability

Up to now it has been necessary to design and implement a private network employing IP multicasting for any large exercise, evaluation, or experiment that required the efficiency of multicast for many-to-many group communication. Effective with the availability of XOM, it will be possible to "turn on" multicasting across any combination of local area networks that are interconnected by Internet Protocol service. The performance available will of course be dependent on the underlying networks. Experience to date suggests that across networks such as Internet2 and DREN, an XOM system using the current prototype XOM Relay (XOMR) prototype could support tens of subnets with aggregate group traffic up to 5000 messages per second and 1 Megabit per second, while exhibiting latency under 100 milliseconds and jitter under 20 milliseconds. Scaling to higher traffic levels should be possible if the load is distributed across multiple multicast groups, assuming the underlying network has adequate capacity. In addition, XOM can be used with our previously developed Selectively Reliable Multicast Protocol (SRMP) to achieve more efficient transmission of a mix of reliable and best-effort multicast, a function that is not available elsewhere in any form.

3.1.5.3 Maturity

XOM is a new development, based on overlay concepts developed in the networking research community in the past decade. Its applicability has been demonstrated clearly and its concept is very basic: middleware relay agents, deployed one per subnetwork, cooperate to form an overlay "meta network" that replicates the traditional multicast tree and achieves network use efficiency equal to IP multicast. The current XOMR is capable of supporting moderate traffic levels (5000 aggregate messages per second in the multicast group) and soon will be more operationally practical due to enhancement by Web services for registry and routing information distribution. However, reaching the maturity needed for broad Defense M&S use will require an industrial-strength implementation combined with confidence-building demonstration applications.

3.1.5.4 Required Changes

Needed changes include expansion to an industry-academic development team and standardization work, beginning in Web3D (a natural application community) and leading to IETF or other open network standards body formalization. It appears that IETF acceptance of SRMP will need to be combined with XOM due to the fact that the Reliable Multicast Transport Working Group has yet to consider it, and that group is due to be terminated soon, leaving no immediate path to pursue SRMP standardization within IETF.

3.1.5.5 Timetable for Adoption of Changes

FY05 – initial industry team formation; early demonstrations involving five to ten sites; work with Web3D to define a standardizable protocol.

FY06 – scale-up to twenty sites and participate in a major military exercise or experiment; work with IETF to formalize an open standard.

3.1.6 Semantic Web

3.1.6.1 Description

One of the newest initiatives in the evolution of the World Wide Web (WWW) is the specification of standards and technologies to create the Semantic Web. Most of today's WWW is targeted primarily at human readers; the Semantic Web supports both human readers and software agents that can perform automated reasoning, creating a Web of knowledge. The Semantic Web is "an extension of the current Web in which information is given well-defined meaning, better enabling computers and people to work in cooperation" (Berners-Lee, et. al., 2001).

Key technologies comprising the Semantic Web are summarized by the WWW Consortium (W3C) in a Semantic Web Stack shown in Figure 4 (Herman, 2003) (Daconta, et. al., 2003). Brief descriptions of the layers in the Semantic Web Stack are provided below.

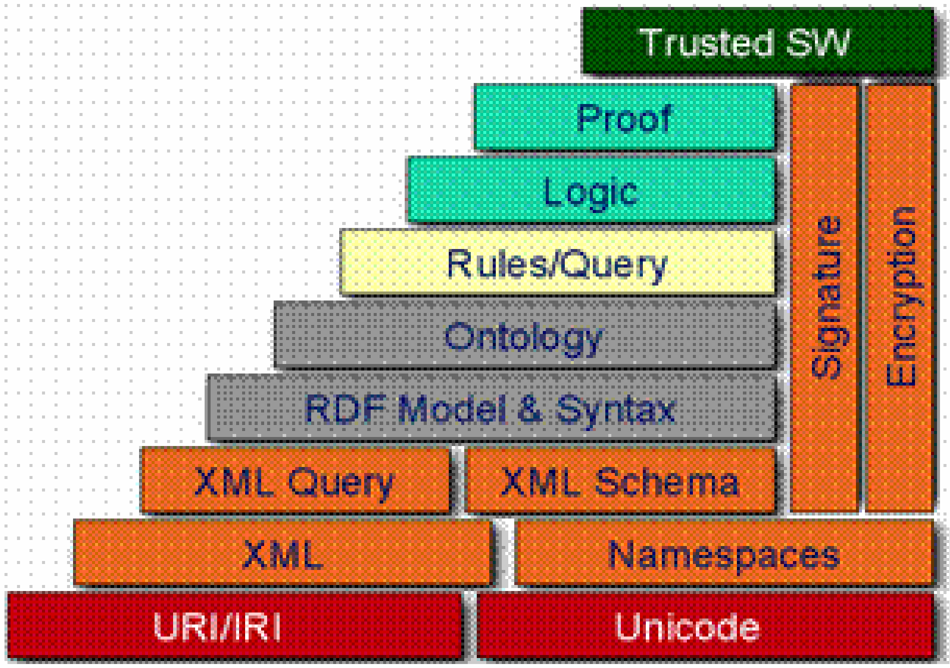

Figure 4. Semantic Web Stack

-Universal Resource Identifier (URI). Any resource on the WWW is identified by a URI. The URI comes in two forms, the familiar Universal Resource Locator (URL), commonly used for web page and web link addresses, and the less common Universal Resource Name (URN), used to provide a unique logical naming of any resource on the WWW without regard to its physical location.

-Unicode. Unicode provides a unique number for every character, no matter what the platform, no matter what the program, no matter what the language (Unicode, 2004). Unicode is required by modern standards such as XML, Java, and ECMAScript (JavaScript), and is the official way to implement the universal character set standard, ISO/IEC 10646 (ISO/IEC, 1993). The emergence of the Unicode Standard, and the availability of tools supporting it, are among the most significant recent global software technology trends.

-XML. XML provides the ability to create new vocabularies to structure, describe, and interchange data, as discussed above. XML enables users to add arbitrary structure to their documents but says nothing about what the structures mean. XML is a subset of the Standard Generalized Markup Language (SGML), as is HTML, which serves as a standard for creating languages (Hunter, et. al., 2003). Whereas HTML has a fixed set of defined tags, XML provides rules for creating an arbitrary set of tags by which an agent (human or software) can describe content in a document. XML is a clearly defined way to structure, describe, and interchange data (Altova, 2003). The structure and content of an XML document can be specified by a Document Type Definition (DTD) or by an XML schema. XML documents can be validated against their respective specifications, as represented by DTDs or schemas. The XML Schema language provides more detailed specification of the grammar of an XML language through range constraints, patterns, and use of XML namespaces.

Since XML enables one to describe data, XML documents themselves become data that can be described. Thus, layers of metadata can be written to describe content, describe the description of the content, describe relationships across content, and so forth to any level of complexity needed. As we will see shortly, this idea is a fundamental building block for the Semantic Web.

-Namespaces. XML Namespaces provide a means for distinguishing an element identifier in one context (namespace) from the same element identifier in another context (different namespace). Thus, XML Namespaces provide a mechanism for deconflicting element identifiers (tag names) in XML documents, allowing multiple XML languages (specified by schemas, for example) to be merged into the same document without confusion. This means that XML languages can be defined for specialized purposes but combined when needed with other XML languages for more complete information. An example would be an XML language for military equipment being combined with an XML language describing a military unit to produce XML documents containing the equipment possessed by certain units. Both vocabularies may have an element called "Name" (i.e., name of the unit, name of the equipment item), but in the combined document, the usage is distinguished by the respective namespace.

-XML Query. The hierarchical structure of an XML document and the identifiable element tags and attribute names facilitate document search. The XML Query (XQuery) project of the W3C seeks to develop a standard for querying XML documents, as well as the next-generation standards for XML selection (XPath2), XML serialization, Full-Text Search, a possible functional XML Data Model, and a standard set of functions and operators for manipulating web data (XQuery, 2004).

-XML Schema. As introduced earlier, XML Schema is a XML-based markup language describing the structure and constraining the contents of XML documents (Geroimenko, 2004).

-Resource Description Framework (RDF) Model and Syntax (RDF Schema). RDF is an XML-based language for representing information about resources in the WWW (RDF, 2004). Resources are anything on the Web that is identified by a URI. The RDF syntax expresses a subject-predicate-object triplet (equivalently, also referred to as an object-attribute-value triple), so that relationships between resources can be declared (i.e., we can create class hierarchies for the classification and description of objects). RDF provides a means to express assertions that form a foundation for logical reasoning. Whereas RDF is a set of rules for defining semantics; RDF Schema is a way of creating vocabularies (Hjelm, 2001).

-Ontology. Ontology is a "formal, explicit specification of a shared conceptualization" (Gruber, 1993). Ontologies provide a "shared and common understanding of a domain that can be communicated between people and heterogeneous and widely spread application systems" (Fensel, 2001). An ontology provides a vocabulary of terms and relations with which to model a domain.

Another perspective on the Semantic Web concept is shown in the Ontology Spectrum in Figure 5 (Daconta, et. al., 2003). The Ontology Spectrum identifies various approaches to describing data providing a scale from weak semantics to strong semantics. Technologies promoted in the

Semantic Web push the community to higher levels of semantic representation so that software can achieve interoperability at a conceptual level.

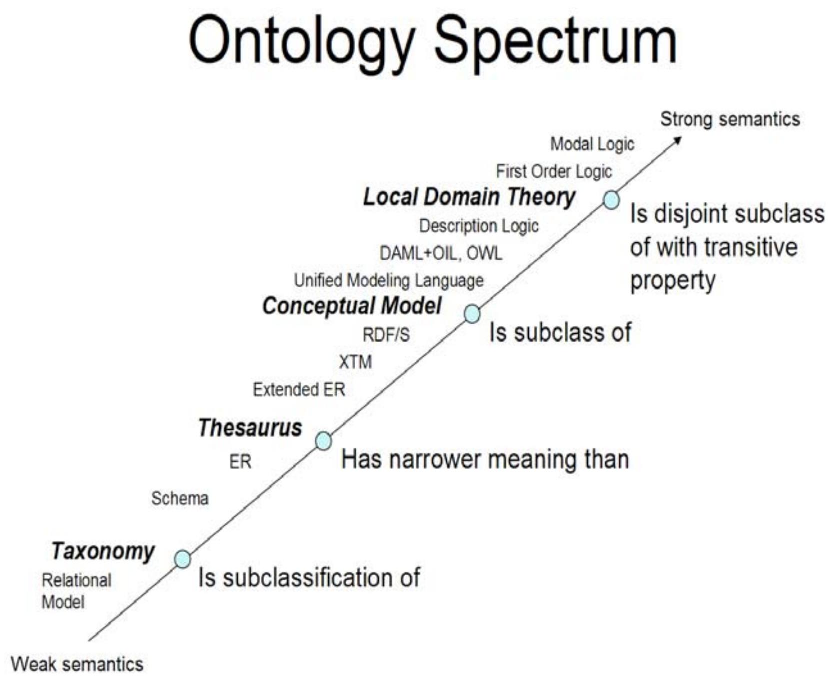

Figure 5. Ontology Spectrum

VMASC is studying to what extent data models based on mutual consensus, in particular the C2IEDM, can serve as an ontology. The study is analyzing the general requirements and constraints for ontologies for unambiguous information exchange and the extent to which a model such as the C2IEDM can fulfill these needs. In addition to this graduate level evaluation, the Battle Management Language (BML) efforts are dealing with similar questions for the alignment of air and land BML in the joint context. NPS MOVES is working with the US Army Engineer Research and Development Center (ERDC) to examine various representations of maneuver networks to establish a conceptual foundation for development of a Common Maneuver Networks ontology to enable simulation and C4I systems to interoperate with maneuver data for analysis, training, planning, and operations conduct.

-Rules/Query. Given the ability to make assertions, rules can be formulated. Rules are considered to be a major issue in the further development of the Semantic Web. They can be used in ontology languages, either in conjunction with or as an alternative to description logics, and they act as a means to draw inferences, to express constraints, to specify policies, to transform data, and other operations. Moreover, a rules layer provides a standard way to query and filter RDF. For example, RDF and RDF Schema can be considered at three levels of abstraction (Broekstra, et. al., 2003):

- Syntactic: as XML documents, can be queried as discussed previously, but this approach is not practical since relationships in the RDF data model are not apparent from the XML tree structure;
- Structure: as a set of triples (object-attribute-value), a number of query languages have been proposed and implemented, but certain RDF Schema statements have been given special semantics that cannot be asserted the same way;
- Semantic: as one or more graphs with partially defined semantics, enabling queries that give access to the RDF Schema-specific contents of an RDF triplet and the structure of the subclass hierarchy.
-

-Logic. The logic layer establishes a formal framework for assertions and inferences.

-Proof. The logical framework provides the basis for software to prove theorems about the domain represented by the ontology.

-Trust. The goal is to establish a "web of trust" where human and software agents can interact and exchange services and data in a trusted environment (hard enough for humans to establish; very challenging for software). The ability to establish trust is built upon the lower layers of the stack and the cross-cutting security enablers, Signature and Encryption.

-Signature. Digital signatures are "encrypted blocks of data that computers and agents can use to verify that the attached information has been provided by a specific trusted source" (Berners-Lee, et. al., 2001).

-Encryption. Sensitive data can be encrypted so that only the intended recipient is able to read the data. Confidence that sensitive data is protected and assurance that interactions are taking place only with intended agents are key enablers to trust.

Some of the other abbreviations in Figure 5 not previously described are defined below (with references for the interested reader):

- ER: Entity-Relation model
- XTM: XML Topic Maps, see (XTM, 2004) and (Garshol, 2004)
- DAML+OIL: Defense Advanced Research Projects Agency (DARPA) Agent Markup Language + Ontology Inference Layer (OIL); see (DAML, 2001)
- OWL: Web Ontology Language; see (OWL, 2004)

As discussed previously, SOA are rapidly becoming the primary approach to automated business interactions and business process integration in the commercial, government and military arenas. Web services and service-oriented architectures "are going to fundamentally change the way we build our internal systems – the information systems that support our organizations – and how our internal systems interact with external systems" (Barry, 2003). However, while Web services define formal interface contracts describing the message syntax, they do not address the semantics issue; that is, the meaning of the exchanged data is not formally described (Zimmermann, et. al., 2003). For agent-to-agent applications to automate solutions to interoperability problems, they will need to have an understanding of the data being exchanged; not just what it is, but what can be done with it. This realization has spawned research in a

blending of Web services with the Semantic Web, denoted as Semantic Web Services.

3.1.6.2 Area of Applicability

Military modeling and simulation (M&S), together with Command, Control, Communications, Computers and Intelligence (C4I) systems, continue to represent extremely challenging areas of computer application today. Few applications hold such importance in terms of material and human costs than the strategic, operational, and tactical systems used for military acquisition, training, analysis, planning, rehearsal, execution, and after-action assessment.

Two overarching challenges to military M&S include:

- Interoperability: The capability of a system (e.g., simulation) to automatically, without human intervention, provide services to and accept services from other systems, and to use the services so exchanged to enable the systems to work together to achieve a desired outcome (adapted from (MSMP, 2004)).
- Composability: The capability to select and assemble reusable simulation components in various combinations into software systems to meet user requirements (Petty, 2004).

An example of a specific challenge spanning both of these overarching challenges is Rapid Scenario Generation. Sub-objective 1.6 (Automating M&S Systems Support) of the Defense Modeling and Simulation Office (DMSO) Modeling and Simulation Master Plan states the requirement as: "Improve the automated workflow and support of M&S Systems (e.g., rapid database development)." (MSMP, 2004) Rapid Scenario Generation is the ability to find and prepare information and materials describing a battlespace to support training, analysis, or mission planning within compressed time frames (particularly for mission planning) and based on operational documents (e.g., training requirements, problem statements, or OpOrders, respectively). There are numerous issues relating to how the necessary information (terrain, maps, forces, assets, behaviors, characteristics, weather, etc.) is identified, posted, discovered, accessed, and composed to form a full battlespace representation for a particular use, including as input data to a simulation or C4I system. The Rapid Distributed Database Development (RD3) is a new program addressing this specific challenge (RD3, 2004).

Existing and emerging Web-based technologies are showing the ability to achieve world-wide scalability, changing the computational environment "from single isolated devices to entry points into a worldwide network of information exchange and business transactions" (Fensel, 2001). This is currently happening at a fairly mechanistic level – the next great technical leap, as always, will be the ability for software to automate routine processes. The enabler for the next technological leap on the Web is the Semantic Web:

> "To date, the Web has developed most rapidly as a medium of documents for people rather than for data and information that can be processed automatically. The Semantic Web aims to make up for this." (Berners-Lee, et. al., 2001)

In the M&S domain, emerging Semantic Web technologies offer opportunities to dramatically improve composability of functional capabilities and interoperability of systems, including interoperability between M&S and operational C4I systems.

Model Based Data Management

In (Tolk, 2004c), the author proposes use of a reference data model and describes Model Based Data Management (MBDM) activities that need to be performed to map data across software services; namely (refer to that paper for details):

- Extension of property values
- Enhancement/refinement of property values
- Different grouping of property values
- Extension of propertied concepts
- Enhancement/refinement of propertied concepts
- Different grouping of propertied concepts
- Extension of associated concepts
- Enhancement/refinement of associated concepts

These activities provide a roadmap for development of automated support to the cognitive effort needed to perform the activity. The key issue here is semantic mapping across diverse systems. Clearly, the simplest notion is for all systems to use the same knowledge structures and algorithms to achieve complete conceptual interoperability. However, just as the idea of a single human language has never been achievable, a single C4I/M&S language is not practical as concepts and approaches rapidly evolve to address changing operations and the ever-changing threat. More reasonable is creation of an extensible capability for diverse C4I/M&S languages to be semantically interchanged through relationships to top-level concepts for the domains of interest (upper ontologies). Any approach to semantic interoperability needs to enable even the top-level concepts to adapt and evolve over time. The ideas of MBDM are now tool supported (e.g., using Altova products XML Spy and MapForce) and were applied within the BML projects “Extensible Battle Management Language (XBML)” and “Air Operations Battle Management Language (AO BML)” as alternatives to the solutions implemented by the industry partners Atlantic Consulting Services, Inc. (ACS) and Gestalt, LLC. C2IEDM web services developed for information storage and data mediation use MBDM to map XML interfaces to the C2IEDM tag set as defined for the coalition namespace in the DoD XML Repository and to store and/or retrieve information into/from a MySQL C2IEDM compliant database, which can be accessed via web services.

The C4I-M&S Reference Object Model (CROM) effort over the past few years has been working toward an alignment of C4I and M&S data models, leading to description of portions of a C4I object model using the C2IEDM. While an important early step, work is needed to push the semantic modeling further up the ontology spectrum than the CROM efforts to date by moving from UML representations to ontological representations using emerging standards such as OWL.

In (Blais and Lacy, 2004), the author describes a simple example of the nature of the problem by considering the representation of minefields in the OneSAF Objective System (Henderson and Granger, 2001) abd C2IEDM. This example deals with a *conceptual* level of mapping – how the data *models* align (or don’t align). Another level of mapping is at the *instance* level – how specific *data* aligns (or doesn’t); i.e., determining that a particular item in one data base corresponds to a particular item in another data base. Both are critical issues to be addressed

through Semantic Web approaches. Humans are able in most cases to perform data mappings across representations, although sometimes with great difficulty. The new challenge is to provide enough meta-information about the data to enable software to be able to automatically perform these mappings. Evolution of the Semantic Web is addressing such needs.

DMSO M&S Objectives

The DoD Modeling and Simulation Master Plan (MSMP) previously cited presents key challenges that need to be addressed to achieve long-term solutions, including:

- E5.7.2.2. M&S models, simulations, data, information, and resources are hard to find, access, and use.
- E5.7.2.3. Barriers to the effective use of M&S resource repositories such as lack of unambiguous content description standards, marking standards, incentives to provide and maintain information, and government ownership.
- E5.10.1. Consistent, unambiguous interchange capabilities to support dynamic interactions and interdependencies of humans, systems, and the disparate elements of the natural environment.

The MSMP also identifies a number of DoD M&S objectives relevant to Semantic Web research:

- E3.1.1.5. Sub-objective 1.6: Automating M&S Systems Support. Improve the automated workflow and support of M&S systems (i.e., rapid database development).
- E3.1.2.3.1. Establishing standard taxonomies, ontologies, and common object classes (e.g., individual equipment, vehicles, aircraft, missiles) for systems FoS (Families of Systems), and SoS (Systems of Systems) representation.
- E.3.1.2.4.6. Establishing a system to publish information about, search for, share, and apply distributed simulation environments.
- E3.1.4.2.3. Establishing a readily accessible information resource that includes, but is not limited to, applications, algorithms, protocols, standards, and data sets.
- E3.1.5.2.4. Develop the tools and underlying infrastructure to rapidly and accurately identify, access, acquire, collect, analyze, synthesize, generate, and disseminate unclassified and classified scientific, technical, and operational support information required to support modeling and simulation on a worldwide basis.
- E3.1.5.3.1. Publish, find, and access distributed simulation capabilities.

These challenges and objectives fall within the realm of Semantic Web research as they involve the description and discovery of Web-based (open or military, classified or unclassified) resources.

Rapid Distributed Database Development (RD3)

The Rapid Distributed Database Development (RD3) program has been initiated to address many of the MSMP objectives identified above. RD3 envisions an integrated system for identifying, collecting, manipulating, storing, and retrieving data in a usable form to support Joint requirements for planning, training, mission rehearsal, and experimentation.

It is recognized that DoD is rapidly undergoing an information transformation, promoting the use of Web technologies such as XML for describing information and Web Services for creating environments for business process and application access-on-demand. Much work has been done and continues to be done in describing scenario content in XML representations, such as the scenario description language used by the OOS, employment of the C2IEDM as a common representation for data exchange across C4I systems and simulation systems, and Battle Management Language (BML) for unambiguous expression of plans and orders for understanding by humans and software (Hieb, 2004). Furthermore, recent work takes the representations to higher ontology levels (refer to the ontology spectrum shown earlier), moving beyond XML and XML schema representations to descriptive layers that will enable software to perform reasoning on the data, setting the stage for automation of processes that have been heavily human-centric in the past; in particular, see (Lacy and Henninger, 2003) and (Lacy and Gerber, 2004).

Research has been proposed focusing on determining descriptive techniques that will enable software to reason from structured scenario descriptions to discover and assemble web-based resources appropriate for the planning, training, mission rehearsal, or experimentation objective at hand. This requires research at both ends of the process – description of the resources themselves for publication in the web environment and identification of the resources in the scenario descriptions in such a way that the appropriate resources can be found and assembled automatically by software.

The RD3 database production process exhibits a need for strong semantics representation across various activities. For example, Event Planners need to be able to describe the situation and scenario in a form (e.g., XBML taken to a higher level of the ontology spectrum) that can be used by software to assist/automate operations performed by the Database Analysts at the next level in the process. Strong semantics are needed to support the process of creating the integrated source data through correction, alignment, merging, correlation, and analysis. The authoritative source data will likely reside on widely distributed resources on the World Wide Web and future military classified/unclassified equivalents (i.e., employing identical standards and technologies). Resource publishing and discovery will be enabled by Semantic Web research in progress.

For automation of the assembly process, there has to be explicit or inferable relationships across the resources and the event specification. For example, the scenario definition may indicate a locale for the operation and the forces involved. The assembly software must have sufficient ontological information to be able to infer the resolution of terrain or weather data needed and possibly the level of representation of the forces that meets the needs of the event (i.e., force aggregation at some hierarchy level based on the event audience/participants). To assist Event Planners in identifying and obtaining the precise resources needed to populate the event specification, software must be able to make inferences as to the resources needed to meet the requirements of the event. Whereas the event specification may describe classes of information needed, software needs to make decisions regarding the actual data and services instances that will be accessed, collected, assembled, and possibly transformed (e.g., for use in a specific simulation).

In all cases, well-defined semantics across the several layers of the problem description are needed to provide unambiguous content description that can be operated on by software. One can envision various ontologies being involved in the scenario description process; e.g., one (or more) describing the natural environment, one (or more) describing military and non-military forces to be represented in the scenario, one (or more) describing weapon characteristics, one (or more) describing time and setting of the scenario, and so on. A challenge to be faced is making ontologies interoperable through ontology mappings; i.e., matching corresponding concepts in whole or in part (Burstein, 2004).

It may be possible to consider such limited scope domain ontologies as parts of a larger whole that is expressed at a higher level of abstraction, possibly derived from a foundational ontology (a conceptualization that contains specifications of domain independent concepts and relations based on formal principles derived from linguistics, philosophy, and mathematics). (Mika, et. al, 2004) Thinking long-term, tying the abstraction of a scenario into common structures such as the Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) (Gangemi, 2003) or the Suggested Upper Merged Ontology (SUMO, 2004) permits the scenario concepts to cross over into a broader domains of application. One application may be military scenarios playing a role in a larger-scale political "game" in which the planned military operation will influence diplomatic planning and actions.

Recommended Semantic Web activities in RD3 include:

- Investigate current and proposed approaches to formalizing the situation and scenario definition (event specification). Propose and design higher ontology descriptions as needed to enable software to reason about the data requested.
- Investigate current and proposed approaches to formalize the description of resources. Consider Semantic Web research leading toward the "Web of trust" in addition to informational aspects of the resource description (e.g., determining if a posted resource truly represents what its description implies). As needed, propose and design descriptions of the resources that promote discovery and application.
- Propose and design ontology layers and inter-layer mappings that may be needed to enable software to automatically identify resources from the event specification.
- Track developments in the Semantic Web community for application to the research.

3.1.6.3 Maturity

Foundational standards are well established; others are becoming more solid as the community focuses on the Semantic Web initiative. A recent initiative in Europe called the Semantic Web for Advanced Development – Europe (SWAD-Europe) has provided "thousands of developers" with tools to create, store, and view Semantic Web data, indicating the rapid adoption of the concepts by developers world-wide. (Miller, 2004) The challenge is community education together with identification of appropriate standards, techniques, and tools to rapidly introduce the capabilities into ongoing M&S programs.

3.1.6.4 Required Changes

In parallel with ongoing WWW developments, the M&S community in recent years has initiated efforts to determine how the enormous investment in Internet and Web technologies can be

exploited for military M&S purposes. The XMSF project is providing the technical basis for transformational interoperability via XML data and messaging interchange, profiles, and recommended practices for Web-based M&S. Broad technical interoperability is enabled by open standards, XML-based markup languages, Internet technologies, and cross-platform Web services supporting diverse distributed M&S simulation applications.

In the Technical Challenges workshop in 2002, the XMSF project acknowledged that development of ontologies as a basis of meaning is a fundamentally difficult area that has seen much research progress in recent years as part of the W3C's Semantic Web (Brutzman, et. al., 2002). The first requirement in the area of ontologies is to allow definition and approval of complementary taxonomies that can be applied across multiple XMSF application domains. This will allow for the consistent classification of data and services via precise vocabularies. A subsequent requirement is to establish consensual common meaning. It does not suffice for there to be agreed-upon meaning within a group, but to be truly useful, there needs to be a mechanism for defining the equivalence of terms between groups (ontology mapping). This will allow for both extensibility and for interoperability. The Defense Advanced Research Project Agency (DARPA) Agent Markup Language (DAML) project has established an ontology repository for common service representations (DAML, 2004). For XMSF, RDF and OWL are of particular interest as applicable standards for ontology expression. In practice, the NATO-developed C2IEDM information-exchange data model is being exploited for tactical operations. It will be particularly interesting to consider the implications of ontologies like C2IEDM that help to establish commonalities between services and coalition partners. Development of effective ontologies for military operations orders (which contain tactical versions of the "who, what, when, where and how" of an operation) is a strategically important application area deserving dedicated further work.

Semantic Web concepts and standards can be addressed in XMSF Profiles to assist the M&S community in integrating these powerful techniques into their existing and emerging systems. The XMSF profiling work can be taken to the next level of detail by not just identifying what Web-based technology is being employed, but by providing characterization of how the technology is being employed. For application of Semantic Web concepts, characterization of the Implementation Profile can include further detail about the position of the application along the ontology spectrum, leading to further detail identifying registered schema, namespaces, or ontologies employed as well as modeling methodology and tools used. This information alone reveals a wealth of insight into opportunities to interoperate with the subject application. Furthermore, XMSF profiles should be expressed with sufficient semantic content to enable software to compare profiles and make inferences regarding the level of interoperability that can be achieved between systems described by those profiles.

3.1.6.5 Timetable for Adoption of Changes

Initial efforts can be taken in current development of emerging systems (e.g., OneSAF Objective System, COMBAT^XXI) to create a better foundation for incorporation of Semantic Web concepts; namely, to advance the level of data modeling to representations in RDF at a basic level and OWL at a more sophisticated level. The community cannot afford to proceed with delivery of these new systems and be faced again with future retro-fitting to provide needed interoperability capabilities. Implementations that are already modeled to the level of relational models, XML

schema, and Entity-Relation Diagrams can readily be converted to RDF notation. Work is needed to provide automated tools to facilitate this process to the fullest extent possible.

Continued research and application of Semantic Web technologies are fundamental to further automation of processes to meet today's primary challenges to military modeling and simulation.

3.2 Experimentation and Demonstrations

Under XMSF tasking, the Partners planned and coordinated a show floor booth (#2249) at the 2004 Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) in Orlando, FL to provide presentations and demonstrations of XMSF relevant technologies and capabilities to the community. Booth participants featured XMSF partners and contributors George Mason University, Aniviza, Yumetech, Media Machines, and the Web3D Consortium. In addition to the principal XMSF booth, XMSF Partners were located at the Defense Modeling and Simulation Office (DMSO) booth (#530), ODU/VMASC booth (#2418), and SAIC booth (#2605). Other contractors working with the XMSF project also appeared on the show floor, including Vcom3D (#243) and Planet 9 Studios (#1122).

While the majority of the cost was provided by DMSO under XMSF project funding, NAVMSMO, MOVES Institute Delta3D project, and NPS Distance Learning Resource Center (DLRC) made contributions to help offset the overall cost. The Delta3D project is integrating open source software to create an open source game engine for use in military developments, principally relating to networked virtual environments for training systems. DLRC is engaged in development and delivery of military education through online instruction.

In addition to DMSO, various portions of the systems and capabilities demonstrated at the conference were supported by the following sponsors: Joint Advanced Distributed Learning Co-Laboratory (JADL Co-Lab), Naval Air Systems Command (NAVAIR), Defense Threat Reduction Agency (DTRA), USAF Joint Synthetic Battlespace (JSB), Joint Forces Command (JFCOM) J9, OPNAV Assessment Division (N81), Naval Undersea Warfare Center (NUWC), U.S. Army Engineer Research and Development Center (ERDC), U.S. Army TRADOC Analysis Center Monterey (TRAC-Monterey), Sonalysts, Inc. and Web3D Consortium.

Presentations and demonstrations provided in the XMSF booth at I/ITSEC included:

Extensible Modeling and Simulation Framework (XMSF): Overview of the project objectives and achievements (Dr. Don Brutzman, NPS MOVES Institute)

Extensible Battlespace Management Language (XBML) and XMSF Overlay Multicast (XOM) – refer to Sections 4 and 5 of this document for details **(**Dr. J. Mark Pullen, GMU)

Xj3D: Open Source Implementation of the X3D Graphics Language (Alan Hudson and Justin Couch, Yumetech, Inc.)

Online Mentors for Language Training and Cultural Familiarization (Jeffrey Weekley, MOVES Institute Research Associate and Computer Science Masters student
Dr. Ed Sims, Chief Technology Officer, Vcom3D, Inc. and Dr. Luba Grant, Defense

Language Institute (DLI))

Scenario Authoring and Visualization for Advanced Graphical Environments (SAVAGE): On-Line Library of X3D Military Models and Authoring Tools (Jeffrey Weekley, NPS and CS Masters student)

Anti-Terrorism / Force Protection (AT/FP) Planning Tool (Jeffrey Weekley)

Semantic Interoperability: Data Mapping and Ontology Development (Curtis Blais, NPS MOVES Institute Research Associate and MOVES Ph.D. student)

Combat Model Interoperability using Web Services and Discrete Event Simulation (DES) Simkit Library: N81-sponsored Project to Transform Analytical Modeling (John Ruck and Ed Bryla, Rolands & Associates Corporation)

Visual Simulation Toolkit (Viskit): Graphical User Interface for Rapid Simulation Development (Rick Goldberg, Aniviza)

Autonomous Underwater Vehicle (AUV) Workbench: Open Standards 3D Visualization and Physics-Based Modeling (CDR Duane Davis, USN, NPS Computer Science Ph.D. student)

Sonar Visualization for Multi-Platform Net-Centric Undersea Warfare (CDR Duane Davis)

NPS Interactive Web-Based Media Elements: Web-based exercises and animations for NPS online course modules (Kari Miglaw, OCL NPS, Dale Courtney, NPS, Ann Igoe, DLRC (OCL NPS), Dianna Beardslee, DLRC (OCL NPS))

Flux: Reusable Modeling & Simulation Components Based on Open Standards (Tony Parisi, President, Media Machines)

Additional presentations and demonstrations were provided in the partner booths at I/ITSEC, in particular:

XBML/AO BML: C2IEDM based information exchange in support of Battle Management Language efforts for land and air forces (VMASC booth)

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4 XMSF OVERLAY MULTICAST

4.1 Introduction

Growing demand for use of web-based services in large scale real-time distributed simulation virtual simulation (RT-DVS) systems and other real-time applications is fueling extensive research into overlay multicast protocols. These applications demand Quality of Service (QoS) and many-to-many multicast services that are not available in underlying Internet services today and are not likely to be offered as an open network service in the near future. This section describes the requirements specification and proposed design of an overlay multicast protocol designed to support many-to-many multicast for RT-DVS applications, Extensible Modeling and Simulation Framework (Brutzman, et. al., 2002) Overlay Multicast (XOM).

We define the overlay multicast middleware as the XOM Relay (XOMR) where relay implies forwarding of messages to designated destinations from authorized sources. XOMR is an overlay multicast protocol designed to support efficient, reliable many-to-many multicast transmissions on top of existing network protocols such as UDP/IP for real time distributed visual simulations. It is based on the notion of a multicast host which controls all aspects of group communications as a service to supported applications.

Visual space management in real-time distributed simulation and supporting communications systems are evolving toward Web based services and XML tagged object characteristics. The throughput required for communicating object status updates is potentially extremely large, consisting of thousands of updates to simulation objects per second. Receivers within a group must be able to support a large number of simultaneous receivers per transport group with good scalability. A typical receiver set could be required to support objects on the order of 1,000 - 10,000 simultaneous objects per group, or even more. These object updates typically have packet sizes around 100 bytes without tag or other protocol overheads. RT-DVS are run on heterogeneous set of workstations with differing processing and display capabilities, traveling over a heterogeneous network with capacities varying by many orders of magnitude between the initial down link and the slowest end user.

The simplest syntax definition for the protocol is that a message *m* is sent by process *p* and the reception of *m* is by process *q* at one to many recipients. In order to add a level of QoS, by queueing algorithm, the XOMR provides for the arriving of *m* at an incoming channel from the application interface and provides for queuing on the sending side to the network, by process *p*. The remainder of this document provides the following definitions for the XOMR:

- The service requirement/specification—what service is provided
- Assumptions about the environment in which the XOMR protocol must perform
- Specification of the XOMR protocol with a summary of the key routing and control procedures/rules

4.2 XOMR Design Goals

The XOMR:

- Should not require support from routers or operating systems in order to preserve ubiquitous deployment.
- Should be compatible with evolving IP and Multiprotocol Label Switching (MPLS) multicast services as they are deployed in the Internet and be able to use these services automatically in the underlying networks as they become available.
- Uses central registry service and the location of the registry service should not impact overall performance of the XOMR.
- Will be self organizing in the sense that configuration is limited to selecting a registry.
- Uses layered design to indicate the logical structure of the XOMR protocol by separating tasks. Define the problem, the service to be performed at every layer, the external functionality, and the internal functionality.
- Uses routing middleware that is both scalable and decentralized, e.g., not dependent on a central or root services for routing functionality.
- Is based on standards and portable abstractions of the system with network-specific advantages including scalability, fault tolerance, and resource availability easily utilized without any concerns about their underlying infrastructure and resources
- Transmission errors are handled at a higher layer such as using SRMP or at an application layer.
- Uses system aware messaging so that changes in system status can proactively result in network/application adaptation
- Run time environment can support multiple resources scalably
- Is able to deliver/manage QoS to multiple simulation/applications
- Employs mechanisms to adapt and efficiently use system resources
- Uses application knowledge of DVS to tailor design and implementation
- Uses local algorithms to collectively achieve a desired global effect. Example: Some form of explicit congestion notification could be used for dynamically regulating admitted real-time sessions in the face of network congestion/network dynamics, to take advantage of the network awareness characteristic of RT-DVS applications.
- Middleware should be light in terms of computation and communication requirements
- Middleware is designed to smartly trade the QoS of various demands against each other.
- Translates application level performance requirements into network performance requirements
- Identifies optimization metrics for use in resource allocation
- Is not dependent on routers, tunnel end points, operating systems and servers (assumes no proxy approaches)
- Deals with links in a path (tree) that has less/varying capacities yet maintain performance over lower capacity links.
- Is assigned such that changes in topology and network conditions, even node/link failures should not affect the operation of the control mechanism. Topology control problems include
    - Discovering neighbors
    - Identifying position
    - Determining transmission radius (diameter of the overlay)
    - Establishing links to neighbors
    - Maintaining selected structure

    - Maintaining information about nodes
    - Information about service/node access (capacity)
- Is designed not to keep per flow or aggregate state information, in order to not have complex signaling for per flow state information as is the case might be with "stateful" QoS approaches. Example: In stateless network model: real-time, best effort UDP, TCP traffic per hop and end-to-end control algorithms-uses local rate control for best effort traffic and sender-based admission control for real-time UDP.

4.3 XOMR Requirement

Many-to-many multicast transmission is an essential network capability for scalable distributed simulation because the more common unicast approach does not scale well with many-to-many traffic. Also, providing reliable multicast services to RT-DVS is an important requirement to enable use of web based services across open networks like the Internet. These services must include network level quality of service (QoS) for reliability and bounded latency as well as support for many-to-many multicast communications. A number of multicast protocols have been developed over several years to support group communications. Historically, such protocols have focused on supporting applications that typically have one-to-many type data distributions. The obvious examples include streaming audio and video. Even these early protocols have had limitations in support of more demanding types of applications (Braudes and Zabele, 1993). For RT-DVS using web services, these early protocols have proved to be inadequate to support the many-to-many multicast requirement as well as their need for improved QoS.

RT-DVS applications use visual space management in real-time distributed simulation and supporting communications systems and are evolving to web based services and XML tagged object characteristics. The facilities and performance provided by underlying networks represent an important constraint in deployment of XMSF.

The XOMR overlay network requirement is presented in Figure 6. The XOMR is an overlay multicast protocol designed to support efficient, reliable multicast transmissions over existing network protocols such as UDP/IP.

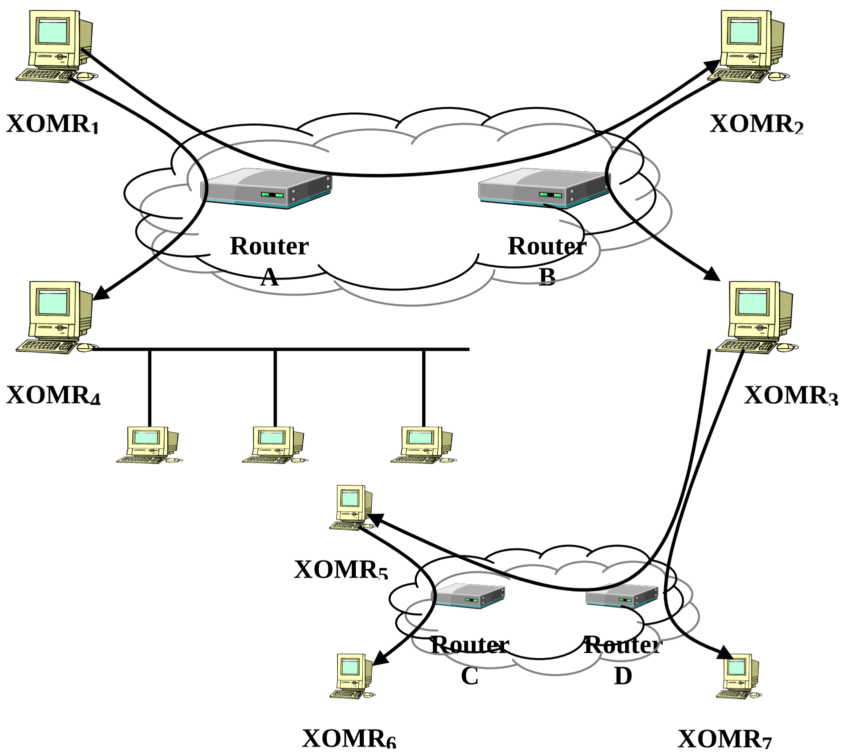

Figure 6. XOM Overlay

Widely deploying RT-DVS across many organizations with large numbers of applications requires robust multicast networking services that are invisible to end users. The proposed approach to XOMR recognizes that underlying networks servicing this broad range of users implies networking of end users that have a wide range of network capacities and may include wireless media and low bandwidths to modern broadband networks operating at gigabit speeds. The approach also recognizes that as RT-DVS applications move toward advanced technologies such as XML-oriented Web services as well as agent-based distributed simulations (Wang, et. al., 2003), there will also be a growing need for advanced networking services that are not likely to be available in open networks such as the Internet (Moen and Pullen, 2003).

The XOMR solution must provide the RT-DVS real-time response and predictable network services in order for the end simulation systems to interact within specific delay bounds. Simulation users deployed across the Internet and/or Intranets require low latency, including stringent jitter requirements and high bandwidth demands. Users also desire simplicity in the sense that there should be very little configuration required to allow deployment and establishment of service. The following presents a summary of requirements for the XOMR in four categories: Group/overlay membership management, QoS, Path management, and security.

4.3.1 Group/Overlay Membership Management

- Need to perform three basic functions in group management: address management, service registration, and group membership maintenance.
- Registration services provide the state of all receivers and services. State information includes number of group members, membership updates as members leave and join, the availability of service, group address and group identifier.
- Need to establish and manage membership in a multicast group which implies assigning multicast group addressing scheme for the overlay. All multicast traffic is then delivered to this address(s). This implies that all members of the group must be listening for traffic with this address. The XOMR allows for use of either IGMPv2 (Internet Group Management Protocol) or IGMPv3 locally to manage group membership. The organizational community can choose which to use, but must be consistent across the community. Using IGMPv3 allows implementation of source specific multicast where a host joins specifically to a sender and group pair. This capability allows some level of protection to the host from receiving messages that it did not specifically request to receive.
- XOMR doesn't provide an inherent address management scheme so that an outside authority (supported by the registry service in XOMR) is required to provide the address of the XOMR host. Inherent to XOMR this approach is a requirement for an address assignment authority to support local served hosts and provide a service to map multicast requests to an overlay IP path.
- There should be no explicit set-up processing between the sender and the receivers prior to the establishment of group communications. The XOMR mechanism is required to pass the multicast group (IP) address to the XOMR of the associated receivers. The receivers' XOMR will have established support for the address prior to transmission in order to receive the data.
- To add a new user to an existing group, the new receiver must first communicate directly with the sender via supporting XOMR using a mechanism to join a group and exchange relevant information such as the group address. The sender then requests the XOMR to add the new receiver, with the basic connection set-up processing invoked as before with the new connection completed only if there is sufficient capacity to process the user.
- XOMR group membership can be closed by either the sender or the receiver. When the last receiver along a path has been removed, the resources allocated over that path are released. When all receivers have been removed, the sender is informed and has the option of either adding a new receiver or tearing down the group.
- Connection set-up involves negotiation of the path capacity (access capacity) and latency parameters between the sender XOMR, intermediate XOMRs, and receiver XOMRs. If the requested resources cannot be made available, the sender is given the option of either accepting what is available or canceling the connection request.

4.3.2 QoS

- Diversity and adaptability must also be accommodated by trading quality of service (reliability. latency, and possibly jitter) with the capacity of the access link. Multicast support for quality trades can be realized either through the use of different multicast groups, and/or with prioritization of access capacity in the overlay. Reliability for multi-class traffic

can be accomplished through use of a protocol such as SRMP on top of the multicast overlay or queuing on the send side based on class of traffic.

- The XOMR does not provide a flow control mechanism in the context that might be used for bulk data or file transfer. SRMP or equivalent higher layer protocol is expected to provide a Flow control mechanism to regulate the quantity of data placed on the network based on feedback from the XOMR for these type of applications.
- The XOMR provides rate control for access to the underlying network service. The service is necessary to allocate available path resources and capacity in such away that maintains the minimum negotiated QoS for the relay agent. Two classes of service are supported: priority and best effort. Using two classes provides a mechanism for application layer to designate priority under congested or constrained conditions. The rate control mechanism also must provide feedback to the higher layer protocol for application layer flow control. The objective is to provide rate control from the global network perspective based on the costs of network resources used on a per flow or group basis.
- The XOMR specification allows the user to determine whether multicast transfers are unreliable or reliable, where reliable transfers are defined to provide a "high-probability of success of delivery to all receivers". SRMP can provide the mechanism to manage this capability and sends the request to XOMR. SRMP, as a transport protocol, runs in the application host.
- The XOMR, as an overlay, provides level of guarantees end-to-end for capacity and latency. The guarantees results from implementation of rate control where the XOMR dynamically manages the path, ensuring that the available capacity is managed at optimum for the overlay. The enforcement policy ensures that the same path is followed for all transmissions and prohibits new connections over the network unless there is sufficient capacity to accommodate the expected traffic. This is accomplished by maintaining the statistical state of all connections in the XOMR relay host.
- The XOMR must acknowledge and be able to respond to the introduction of priority messages above already allocated capacity. The approach is implementation of a conservative statistical approach to capacity allocation where bursts of priority traffic will be allowed within the limits of the current negotiated QoS (Simon, et. al., 2003).

4.3.3 Path Management

- The XOMR protocol suite requires routing support for four functions: path set-up, path tear-down, packet forwarding, and prioritized packet loss due to congestion.
- The routing tables must maintain both the multicast group address and the forwarding path on each outbound interface in order to make appropriate routing decisions.
- XOMR receive path set-up requests as required when new members join a multicast group, which specifies the incoming and outgoing interfaces, the group address, and the QOS associated with the request. When the message is received, XOMR establishes a path between the server and the receiver, and subsequently updates the multicast group state table. Alternatively, the service can be aggregated paths, and not provide sender based trees.
- Path tear-down requests also are propagated through the XOMRs when group membership changes or QoS changes no longer require data to be sent over a given route. These are used to inform XOMRs of both deletions of QoS for a given path and deletions of entire paths. The purpose of the message is to explicitly remove routing table entries in order to minimize

the time required to stop forwarding multicast data across networks once the path is no longer required.

- Interface processes perform send and receive functions between XOMRs across the external network and with application hosts on the attached subnetworks (LANS).
  - The XOMR provides a connectionless service—connectionless implies sending messages without permission hence buffer management/overflow are required at the receive side application layer.
  - The XOMR provides for two levels of priority traffic: Class 0, no priority and Class 1, priority.
  - Queuing mechanism for sender/receiver interface.
  - Local control has to rely on the existence of independent, end-to-end algorithms that can "sense" and react to the distributed, local actions.
  - Provide for resource management by periodically gathering and updating information about the service/network

4.3.4 XOMR Security Requirements

An important question is how much security the XOMR should provide. Is it adequate to provide group authentication or do need to provide source authentication? Group authentication implies that the message originated within the group and has not been modified by an entity outside the group. For sender authentication, it is implied that group members would like to know for themselves the sender of the message.

If we were to apply a systems approach, then we would like to use concept of signatures to detect and enable legitimate requests, denying all other traffic. We would like security to be built in, not something added after the fact. Should it be implemented in the XOMR server?—client relationship? How much integration? Can server approach reduce requirement for layered and thereby increase performance? How do we protect the ability of two processes to exchange data messages in the XOMR network protocol?

- Authentication—two processes exchange messages until each process is certain that it is communicating with the other process
- Privacy—each of the processes uses its security key to encrypt any data message before sending it to the other process
- Integrity—before sending a message, the sending process uses its security key to compute an integrity check for the message and attaches it to the message. This allows receiving process to prove the message arrived without modification
- Non-repudiation—sending process computes digital signature to prove that the message is from the sender
- Authorization—check for authorization to use a requested resource/process

The minimum services available might be to provide a central authentication of senders via the proposed registry services as a "third" party provider. These services would then allow for membership access control at the subnet level via membership authentication and verification in the context of a specific multicast group. We also need to consider protection of the multicast distribution tree; e.g. the routing protocol that manages and controls the tree.

4.4 XOMR Architecture

The architecture for the XOMR is presented in Figure 7 and is purposely designed to be highly modular so that module optimization and alternative strategies for each module can be prototyped for evaluation. The proposed approach for the XOMR overlay is to use UDP as the underlying network protocol and offer services to the application layer for two different classes of services: Class 0-no priority and Class 1-priority traffic.

We employ a priority queuing strategy to give priority to Class 1 traffic and mark Class 0 traffic for discard eligible in the event of network congestion. This approach is consistent with our previous efforts in development of multicast protocols such as the Selectively Reliable Multicast Protocol (SRMP) – see (Pullen, 1999) and (Moen and Pullen, 2001).

Since this approach does not provide error control, any form of desired error control must be added to the client application. The design assumption is that packets are relatively small (<150 bytes) and the underlying network is able to deliver packet guarantees greater than 99% and has reasonable routing path stability on the order of minutes. Reliable transport can also be provided using such protocols as SRMP, shown in Figure 9 as an example interface, where a more desirable reliability is sought but not available to the client application. Alternatively, the application can employ measures such as timeout and retransmission to handle discarded datagrams and sequence numbers so that clients can decide that the datagram is old and amore recent datagram is available or a re-transmission request can be made.

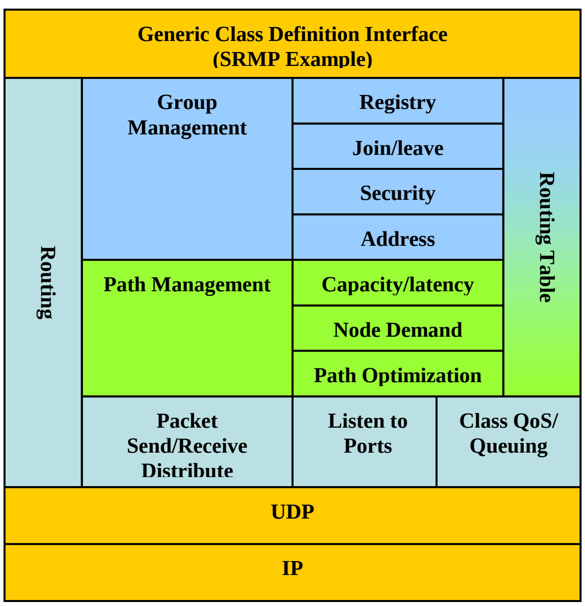

Figure 7. XOMR Architecture

Allocation of a specific XOMR IP address, or network service access point, is not considered part of the XOMR protocol and requires the use of an outside addressing/registry authority to establish an XOMR host. This provides a level of security by establishing an authority that authorizes a source to be a sender which can be used by networked XOMRs receivers for recognition of authorized senders in the network. The registry also will maintain the public

routable IP address of all active XOMRs to be used by the XOMRs to establish efficient overlay multicast paths between XOMRs. The registry also will maintain multicast group membership information. Once an XOMR host is established, internal protocol mechanisms provide for path optimization between XOMR hosts and manage multicast group membership at the local XOMR.

The core of the XOMR is provided in the Group and Path management modules as the result of these activities provide the information for the routing table to be used in making packet forwarding (routing) decisions. A number of approaches are being considered for managing the multicast path overlay and associated groups:

- The XOMRs could provide a service that is independent of group management and essentially provide a path(s) overlay optimized across an open network to other registered XOMRs. Under this model, the path overlay looks like a closed network with all group communications provided as single multicast network similar to Protocol Independent Multicast – Sparse Mode (PIM-SM) specification (Estrin, et. al. 1998). Each user application of the XOMR, then listens for desired group identification communications broadcasted on the local area network hosting the XOMR and discards/ignores unintended traffic.
- The XOMR could provide a service that recognizes group membership dynamics (registered XOMRs that host users/applications identified by group) and provide an overly path optimized for each group. This approach generally is referred to as source-based tree multicast (Fei, et. al., 2001).This implies management and optimization of multiple paths, essentially a path structure for each registered multicast group. The current XOMR prototype uses this approach.
- The XOMR can provide a service that aggregates group traffic across optimized paths between XOMRs as presented in Figure 8. These optimized paths are essentially shared trees and can be optimized for capacity and delay to support aggregated group traffic (Cui, et. al., 2004). This approach also is similar to aggregated group multicast over MPLS and with added features for group management.

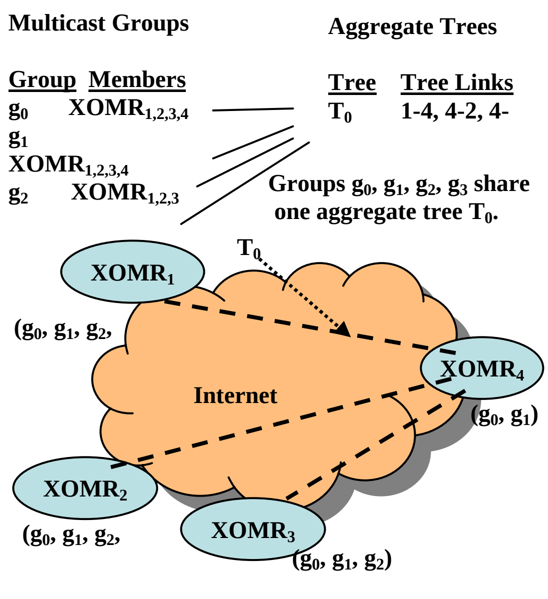

Figure 8. Group Aggregation Overlay

In all cases, once an XOMR and associated address is established, receivers will issue a request to join existing groups using a unique connection identifier that is pre- assigned by the registry. Using this approach, the RT-DVS application is able to control or specify which sources of information are of interest. This is important as we expect that many disparate RT-DVS applications could conceivably be using a local supporting XOMR. This helps protect an individual RT-DVS application from receipt of unspecified or undesired information flows and also aids in minimizing overall network traffic load. This will require that we specify how the XOMR identifier is allocated and how the receivers learn its value the external registry service and supporting protocol.

At the local level, the XOMR manages the receivers' interests in receipt of group messages. This feature allows for a host to report to the local XOMR interest in receiving packets only from specific source addresses and therefore aids in the overall management of group membership and optimization of traffic loads on the network. This approach also potentially adds a level of security to the RT-DVS application as the application is able to discard or ignore messages from unauthorized sources.

We allow for the join request from a RT-DVS application to specify whether the receiver wishes to be a producer of information as well as a receiver, whether the connection should be able to provide the two classes of service (no priority or priority), whether the receiver is able to accept multiple senders of information, the minimum throughput desired, and the maximum data message size. This request information is presented to the supporting XOMR and used in the group join process to support negotiation of the path capacity and latency parameters among the sender XOMR, intermediate XOMRs, and receiver XOMRs. If the needed resources to support the request cannot be made available, the sender is given the option of either accepting what is available or canceling the connection request.

An application request for terminating membership in a group is coordinated through the supporting XOMR. XOMR connections can be closed by either the sender or the receiver. When the last receiver along a path has been removed, the resources allocated over that path are released. When all receivers have been removed, the sender is informed and has the option of either adding a new receiver or tearing down the group.

We have not included in the specification what action the local XOMR should take when the application group is reduced to a single member, but a logical action would be to stop transmission if there are no active receivers and announce this to the registry service.

Our group membership approach assumes that a group definition is based on a specific application running behind an XOMR on the local area network. Multiple instances of an application are supported behind each XOMR, each of which may have different group membership characteristics to include membership in multiple groups. It is also feasible for a RT-DVS application to have membership in more than one group. We present an example in Figure 9. Notice that application B has membership in group 1 and in group 2. In order to maintain efficiencies in packet transmission, we form a new group 3 that is the union of the two groups. We also imply no explicit set-up processing between the sender and the receivers prior to the establishment of group communications. The XOMR mechanism is required to pass the

multicast group (IP/group tag) address to the XOMR of the associated receivers. The receivers' XOMR must have established support for the address prior to transmission in order to receive the data.

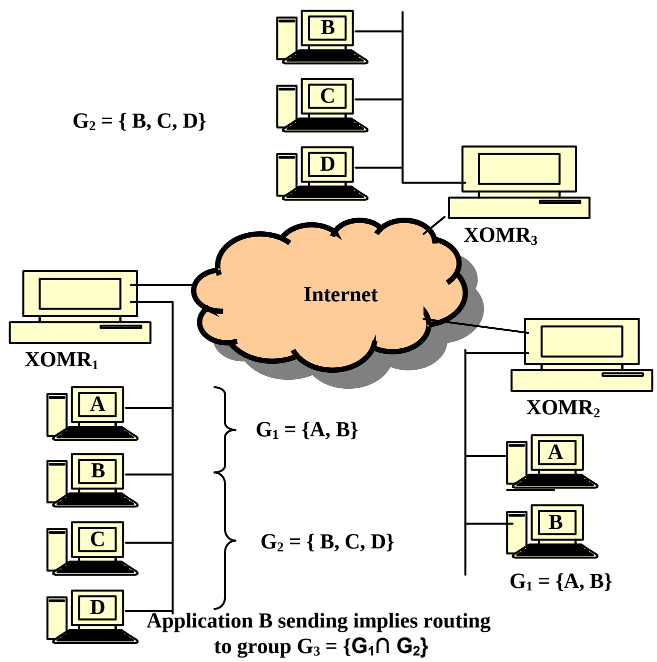

Figure 9. Group Membership

4.5 XOMR ROUTING PROTOCOL

4.5.1 Overview

The routing protocol defines the method used by the XOMRs to exchange reachability information. Its key elements are the use of a central registry and the local XOMR that provides overlay network multicast services to supported RT-DVS applications. The registry maintains a list of all XOMRs in the network and registered RT-DVS application users with their requested group membership, but is not required to maintain the topology of the overlay. The only requirements are that the registry responds/replies to all requests from an XOMR and any XOMR can send messages at least to their neighbors in the overlay network.

The XOMR relies on three steps to build the overlay. The first step is that a joining XOMR must send a request to the registry access to the overlay. Second, the XOMR must discover neighbor XOMRs that are potential candidates for the joining XOMR to establish a network connection with, essentially building and becoming part of an overlay mesh. The third step is for the joining XOMR to establish the services necessary for group management and exchange this information with networked XOMRs, calculate (and update routing table) optimum paths (shortest path tree) for group multicast routing from source to group destinations, and propagate that routing to all other XOMRs.

There are two mechanisms that contribute to global service guarantees. The first is that we put a limit on the out degree of an XOMR using Bollobas definition of the degree of a vertex (Bollobas, 2001, p. 60). That is, we do not allow the construction of more than *n* connections to other XOMRs. This serves to limit the processing demands and network access capacity of individual XOMRs in the overlay. The second is that we threshold the end-to-end overall path delay from a sending XOMR to a destination XOMR and offer only best effort above this threshold to joining XOMRs that do not successfully find an existing XOMR node that is adequate to maintain end-end-to-end path delay thresholds; for example, 110msec threshold in networking latency, based on the fact that 150 msec is representative of human response times for RT-DVS. This can also be accomplished by establishing a network diameter threshold based on (Bollobas, 2001, p. 251) definition of network diameter.

We provide congestion control by providing two levels of service to the RT-DVS application. Class 0 packets have no priority and Class 1 packets have priority. We apply weighted fair queuing giving priority to Class 1 packets in the send queue of the XOMR and discard Class 0 packets randomly during congestion.

Since the XOMR is hosted on the LAN that connects to the supported RT-DVS application, we use IGMPv3 (Cain, et. al., 2002) for group management at the local level.

4.5.2 Network Protocol

Central Registry. A central registry provides a service to register the presence of a XOMR and the participation of an RT-DVS application. The central registry maintains a cache of all nodes participating in the overlay.

a. The registry maintains the IP address of the XOMR, authenticates and audits continued participation in the overlay.
b. The central registry is reachable by all XOMR nodes at all times.
c. In the request for join by a new XOMR, the exchange messages will provide for measurement of round trip delay time (RTT) between the registry and the joining XOMR. The registry will maintain this time and periodically update the information.
d. On request of a new XOMR to join the network, the registry will provide the joining XOMR the addresses of existing XOMRs. The XOMR then randomly polls the existing set of XOMRs measuring the RTT. The responses with the shortest RTT represent the initial best candidates as the nearest neighbors in the overlay. The XOMR continuously performs random polling of known member XOMRs of the overlay, always looking to optimize the selection of best neighbors.
e. The registry provides for registration of the RT-DVS application, authenticates and authorizes relationship to a serving XOMR as a legitimate source/sender, assigns a node ID, and maintains group membership participation based on RT-DVS application request.
f. The registry group management service provides for creation of a multicast group and assigns a group ID using the IP multicast address as the group ID. This information is then made available for source and receiver RT-DVS applications. A joining host source/receiver application can then use the information locally to

indicate to the XOMR a desire to join a group by providing the group ID to the XOMR (XOMRs will use IGMP for this function locally) (Bhattacharyya, 2003).

XOMR Overlay Construction. The XOMR constructs an overlay using a decentralized algorithm by searching for potential target existing network XOMRs to become the child of in the overlay (nearest neighbor). It uses measures of RTT to candidate neighbors to make decisions on joining a parent already in the network.

a. A XOMR wishing to join a multicast overlay sends a request to the registry indicating desire to.
b. The registry authenticates the XOMR against a previously established authorization in the registry and responds to the joining XOMR with a list of all XOMRs in the existing network supporting the desired group membership.
c. The XOMR sends echo requests to *N* candidate XOMR partners resulting in RTT replies.
d. If the candidate XOMR existing connections are less than *n*, the parent XOMR responds with a message indicating availability or else ignores the message.
e. The joining XOMR uses the message exchange to measure RTT to the candidate(s) partner XOMR (s). With the RTT information, the joining XOMR selects the best candidate as the primary connection and selects the second best as an alternate path and responds to these potential parents with acknowledgement of the selected connection and ignores all other responses. The primary partner and the alternate send acknowledgements to the joining XOMR to complete the network join process.
f. The partner XOMR updates the routing table to reflect the new neighbors with measured latency and propagates this information to all its neighbors in the overlay. The result is a connected graph.
g. The XOMR uses the designated primary path unless it is not available in which case it uses the alternate neighbor connection.
h. The XOMR maintains a routing table which maps a node ID to the node IP address and next hop, e.g. neighbor along the path to the distant node.
i. Periodically, a XOMR sends heart beat probe messages to its neighbors to determine if the neighbor is still connected and if necessary, initiates the node join process in the case of disconnected nodes by sending a request to the registry, or by probing known XOMRs in the network.
j. Periodically, each XOMR sends random discover messages to other known XOMRs to discover if a better neighbor (link cost) is available and makes decisions on alternate path choices over using the current path. To support this, the registry must periodically update the list of known XOMRs in the overlay.

Link Delay Measurement. The XOMR develops the link delay data between itself and its neighbors by measuring RTT. This information is shared with the XOMR neighbors and propagated across the overlay.

a. The XOMR collects link delay information shared and periodically updated from neighbor XOMR.
b. The link information is propagated across the overlay so that each XOMR will have knowledge of primary and alternate link delay information between XOMR nodes in the connected graph. It is not necessary to know each link weight in the

graph, if all the nodes in the graph have distinct identities as we imply by the central registry. However, distributed minimum spanning trees are constructed with fewer messages if this knowledge exists at the source node (Gallager, et. al., 1983).

Multicast Tree construction. The overlay constructed by the distributed algorithm is a connected undirected graph with ***N*** nodes and ***E*** edges, with a finite weight assigned to each edge. A distributed algorithm is used at each node to determine the minimum-weight spanning tree (MST).

a. We desire the algorithm to optimize overall performance across the entire overlay. This means optimizing certain objective functions to improve overall quality of message delivery. This quality is typically measured in terms of latency and message loss. The algorithms solve a shortest path problem potentially with many constraints to build a tree connecting the source(s) and destination group members so that minimal message flow occurs in the distribution of the message as well as maintaining optimum or minimum latency form source to each destination. The optimal case is that only a single copy of the message flows on any link in the overlay, meets application latency requirements, and offers some level of reliability. Typical resources that are allocated or that must be optimized are link capacity, host processing capacity, number of links or diameter of the tree, and the degree of a node in the path overlay. In addition, the algorithm must lend itself to supporting dynamic overlays where many multicast group members join and leave in real-time. It is also important to consider the scalability of the algorithm which is made considerably more difficult because end systems typically have limited topological information in which to construct good overlay paths. All these factors are considered in the optimization. A number of algorithms are under consideration such as the constrained Steiner tree (Kompella, 1993) and distributed delay bond algorithms (Jia, 1998). If we run the optimization algorithm at each node, we obtain aggregate multicast paths from each XOMR as a sender to all other XOMRs.
b. The addition of a new node requires the new node initially join as a child node as described in the XOMR overlay construction procedure above. The join information is propagated to neighbor nodes and the new node runs the distributed shortest path algorithm and sends routing table updates to the XOMR overlay.

Node Departure. There are two cases for node departure. A network event may result in the XOMR not being available in the overlay, in which case, the routing algorithm must be able to repair the overlay using the alternate link to nearest neighbor. In the second case, a XOMR may no longer have supported group members and at some point may desire to log off the overlay. This case represents a soft leave and allows for message exchange to effect new path construction without the disruption of service.

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5 EXPERIMENTATION COMMAND AND CONTROL INTERFACE (XC2I)

5.1 Architecture

Composability and web services are both currently hot topics in the M&S community. The flexibility and utility of XML based web services have the potential to transform existing and future distributed simulations, making interoperability a reality rather than a theory, and allowing functionality to be added selectively rather than monolithically. In this section we focus on a layered web services approach for adding authentication, access control, and interest management on top of an existing HLA simulation to enable restricted access from a remote location and reduce unwanted network traffic. We cover the technologies and techniques devised to implement this proposed strategy for an exemplar system, the Experimentation Command & Control Interface (XC2I) project. Although this work was not funded by the DMSO XMSF project per se, it is an excellent example of the application of XMSF principles and illustrates the effect the project is having on development of innovative architectures. The web services interest management portion of XC2I was used by GMU to create a credible HLA workload for XOM. The work provided important insights into Web services traffic versus simple tagged streaming.

In the XC2I, US Joint Forces Command (JFCOM) J9 is seeking to build on the XMSF DCEE (http://www.jfcom.mil/about/fact_dcee.htm) Viewer (XDV) proof of principle to create a distributed software system that can provide both two-dimensional and three-dimensional visualization of entities, aggregates, and terrain, and scale up to large federations of distributed simulations as needed for Joint Urban Operations (JUO). In order to realize these goals advanced features such as role-based access control (RBAC), area of interest management (AOIM) (Morse, et. al., 2004b), and aggregation interest management (AGIM) needed to be developed and deployed alongside existing HLA simulations, in this case federated JSAF systems.

In this section we describe the layered web services architecture used to implement this functionality, and the means by which the different features were composed into a coherent system.

5.1.1 Overview

XC2I has been a collaborative effort between SAIC, GMU, and VMASC with funding from JFCOM J9, the eventual goal of which is to develop a flexible 2D/3D viewer/controller for C2I distributed simulations. The rationale for such a system is one of straightforward economics: it is often neither practical nor effective to relocate ranking officers to simulation centers in order to allow them to view and interact with systems engaged in cooperative simulation events. A single, flexible C2I viewer/controller platform which can remotely connect to these events and be transparently tailored to different systems would allow these officers to view and interact with the simulations without the cost in time and money associated with relocation.
Toward this end, the teammates designed an architecture for such a system and began implementation of a prototype for use with an existing simulation involving distributed JSAF instances modeling JUO scenarios. While this prototype will be used as an exemplar throughout the rest of this section, it is important to note that it was simply a proof of concept

implementation tailored to a specific application, and therefore some of the functionality and capabilities designed into the architecture do not apply directly, and in fact have in some cases yet to be implemented.

The prototype implementation was designed to interact with an HLA-compliant simulation of distributed JSAF instances customized for JUO scenarios and was interconnected using RTI-s. This meant that actual implementations were needed for the access control subsystem, AOIM, AGIM, and an HLA data feed connector built for RTI-s. An additional data feed connector was also required to connect directly to the JSAF Persistent Object Store (POS) as not all required data could be retrieved directly via RTI-s. Finally, a C2IML-aware control system needed to be added, with another connection directly to the POS, to allow orders to be passed from the XC2I client to entities controlled directly by JSAF. The visualization component chosen for the front-end was a modified SOFVIZ 3D viewer, itself a customization of OpenSceneGraph for the Windows platform. Figure 10 shows an overview of the architecture.

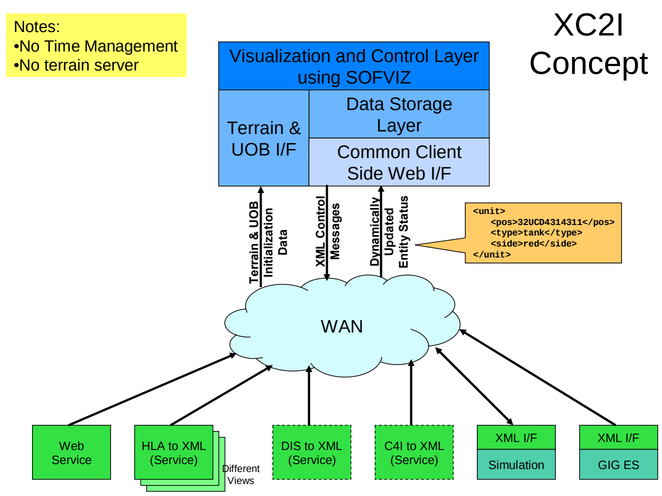

Figure 10. Experimentation Command and Control Interface Concept

As the figure illustrates, a common visualization front-end would be presented to the user, while simulation specific data feeds and control modules would be incorporated dynamically depending on the simulation to which the viewer is being connected.
In order to maintain this level of modularity, two XML-based languages were developed. C2IML links the semantics encapsulated by the C2IEDM specification with XML syntax, providing a well-defined vocabulary for defining AOIM and AGIM. An Access Control Language (ACL) was then developed for the RBAC system. As these languages define the interfaces between the client system and the simulations being viewed or controlled, the XC2I client system can be transparently customized for different back-end simulations given the connection endpoint of the C2IML and ACL aware service endpoints. This is important as different simulations will need different levels of AOIM, AGIM, and security requirements, yet they must all understand the same interest and access control expressions if XC2I is to be effective.

5.1.2 RBAC Architecture

The chief goals in defining the architecture for the authentication and authorization subsystem for XC2I were:

- Defining a globally available identity management system.
- Associating user identities with simulation-specific roles.
- Transparently limiting user interaction with the client based upon the user's available roles.

As an example, a user who is authorized to only view and control blue forces should not be presented with related options reserved for the red or white forces. The sequence diagrams below show how these goals are met by the architecture.

Figure 11 illustrates the process by which a user is authenticated by the access control system. The user begins by entering a username and password at the client login prompt. This information is used to access a globally unique signed certificate that the user must implicitly present to the system, either via a secure keystore on disk or a physical token like a smartcard. It is this certificate that is sent to the access control server and used for identification services. As these certificates are already provided to many DoD personnel as physical tokens and similar authentication systems, and the certificate authority infrastructure is already in place for the DoD, the validity of the certificate can be checked by ensuring that an accepted authority signed it. The identification information found within the certificate can then be used to look up the user privileges on the access control server for the requested system or simulation. While currently this lookup is done using a relational database, other, more distributed identity management systems can be used (e.g., LDAP). Once the user has been authenticated and the available roles determined, the access control server returns a list of roles to the client, where each role is associated with an encrypted, signed token.

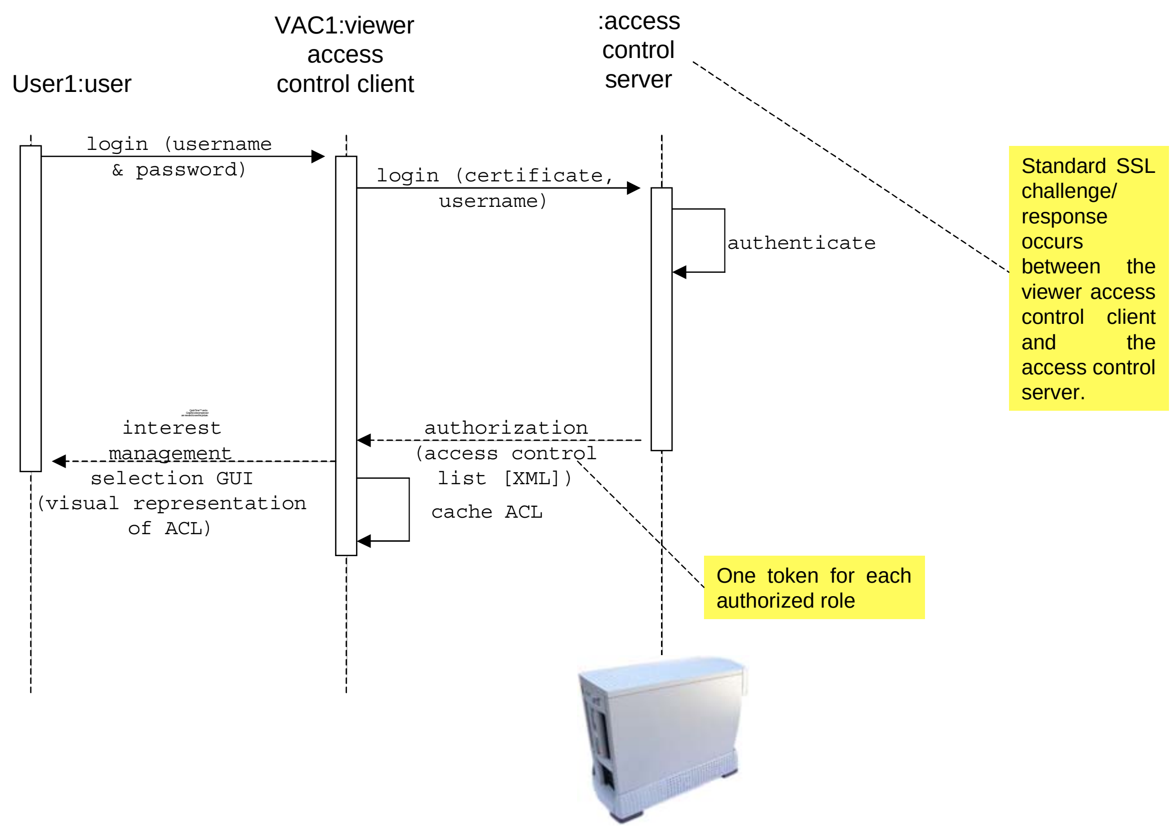

Figure 11. Authorization Sequence Diagram

Once the list of available roles is received, the client offers the user an opportunity to select the preferred role as illustrated in Figure 12. When the user selects a role, the client connects to the simulation via a top level Web Services Interest Management (WSIM) server, requesting that a session be started for the user with the given role. The request includes the token received earlier from the access control server. The WSIM server then verifies the authenticity of the token by verifying the validity of the signature over the token using the access control server's public key. If the access control server's key is not known the WSIM server needs to contact the access control server directly to retrieve it for verification. The token is then sent on to the access control server to be unencrypted and verified. If the token is valid, the WSIM server caches the role information in the session information associated with the requesting client and connects to the simulation. Although these sequence diagrams do not illustrate the processes for responding to exceptions, the traditional exceptions that can be thrown by an authentication system can be incorporated.

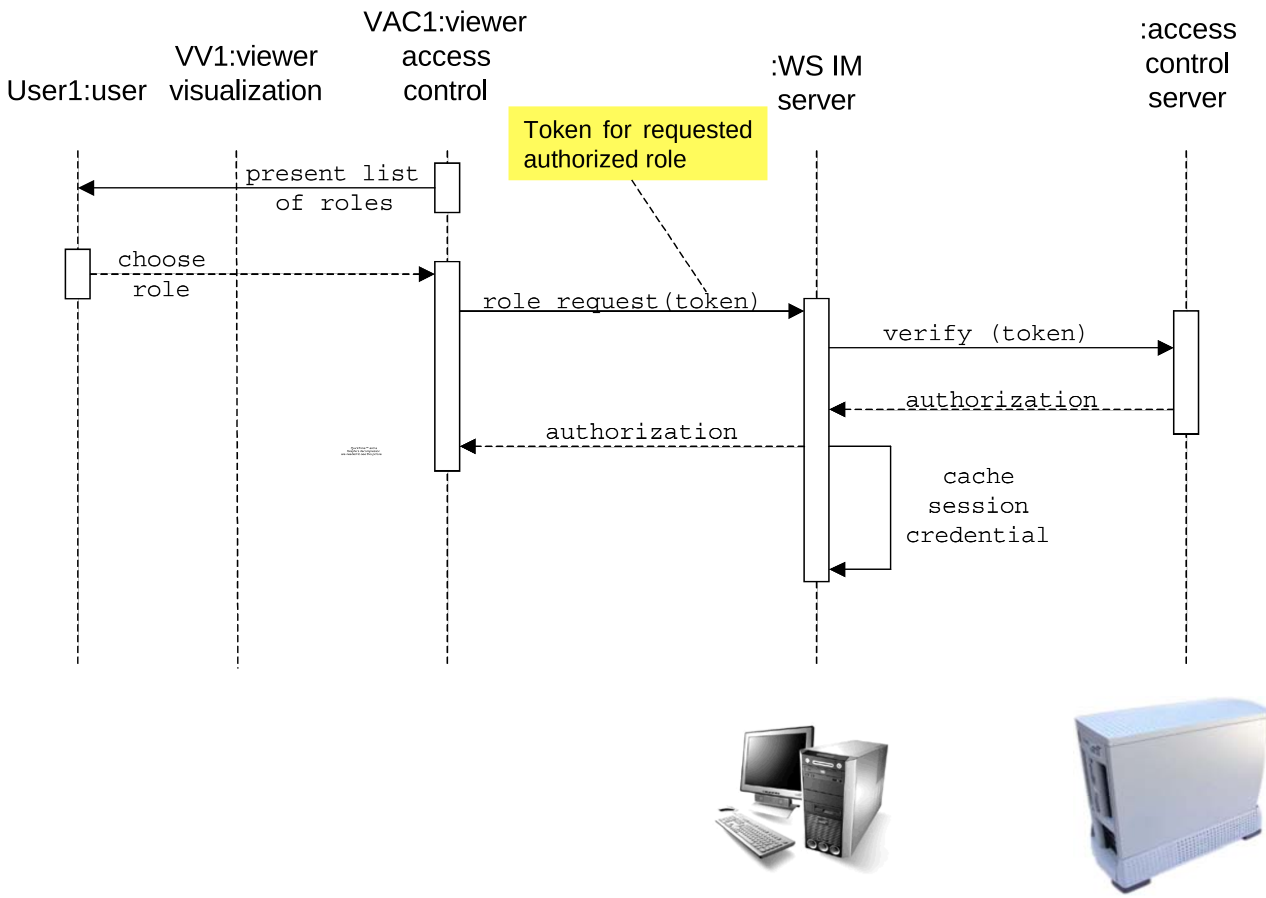

Figure 12. Interest Management Access Control Initialization Sequence Diagram

5.1.3 Components

ACL

The following subsections demonstrate example XML exchanges illustrated in the previous sequence diagrams. The first is the login with the username and certificate in Figure 11. The details of the type of authentication, in this example a user's login, are hidden in the token passed for authentication. This is followed by the access control server's response in the same figure. The third example details the role request with the user's token between the viewer access control and the WSIM server as illustrated in Figure 12.

Initial Client Request

```
<?xml version="1.0"?>
<SOAP:Envelope
    xmlns:SOAP="http://www.w3.org/2003/05/soap-envelope"
    xmlns:ds="http://www.w3.org/2000/09/xmldsig#"
    xmlns:xenc="http://www.w3.org/2001/04/xmlenc#"
    xmlns:wsse="http://docs.oasis-open.org/wss/2004/ 01/oasis-200401-
                wsswssecurity-secext-1.0.xsd"
    xmlns:wsu="http://docs.oasis-open.org/wss/2004/01/ oasis-200401-
                wsswssecurity-utility-1.0.xsd"
```

```
 8        xmlns:acl="http://www.xmsf.com/xc2i/access-control">
 9      <SOAP:Header>
10        <wsse:Security>
11          <wsse:BinarySecurityToken
12            ValueType="...#X509v3"
13              EncodingType="http://www.w3.org/2000/09/ xmldsig#base64Binary"
14            wsu:Id="auth509Token">
15            TdaRFggQeLVoa...
16          </wsse:BinarySecurityToken>
17        </wsse:Security>
18      </SOAP:Header>
19      <SOAP:Body>
20        <acl:AuthorizationRequest>
21          <acl:RequestedServices>
22            <acl:RequestedService URI="xc2i://j9.mil/juo-jsaf"/>
23          </acl:RequestedServices>
24        </acl:AuthorizationRequest>
25      </SOAP:Body>
26    </SOAP:Envelope>
```

Before describing the individual elements of the message above, it is worth clarifying a few details regarding the structure of the message itself. First, the ACL-specific tags are contained within the body of a SOAP message, thereby making the request itself syntactically compliant with current web services standards. Second, a number of different namespaces are utilized in this and the following examples. This is due to the fact that the existing web services security specification builds on a number of other technologies. Line 4 references the W3C XML Digital Signature specification, line 5 the W3C XML Encryption specification, line 6 the OASIS Web Services Security specification, and line 7 the access control language developed for this project. The abbreviations used to reference these namespaces are consistent throughout the examples. Please also note that while a number of encryption and digital signing techniques have been integrated into the language, there was an implicit design assumption that these messages would be transferred over a secure, encrypted protocol (e.g., HTTPS using SSLv3 or TLS).

The request message itself is quite straightforward. Lines 10-17 denote a Web Services Security block containing the client's certificate on lines 11-16. Lines 20-24 make up the actual authorization request. Within this request, lines 21-23 list the services for which the client is requesting access, in this case an XC2I connection to the JUO version of JSAF.

Access Control Server Response

```
<?xml version="1.0"?>
<SOAP:Envelope
    xmlns:SOAP="http://www.w3.org/2003/05/soap-envelope"
    xmlns:ds="http://www.w3.org/2000/09/xmldsig#"
    xmlns:xenc="http://www.w3.org/2001/04/xmlenc#"
    xmlns:wsse="http://docs.oasis-open.org/wss/2004/01/ oasis-200401-
                     wsswssecurity-secext-1.0.xsd"
    xmlns:wsu="http://docs.oasis-open.org/wss/2004/01/oasis-200401-
                     wsswssecurity-utility-1.0.xsd"
    xmlns:acl="http://www.xmsf.com/xc2i/access-control">
  <SOAP:Header>
    <wsse:Security>
      <wsu:Timestamp wsu:Id="tstamp">
        <wsu:Created>2004-05-21T08:42:00Z</wsu:Created>
      </wsu:Timestamp>
      <xenc:EncryptedKey>
        <xenc:EncryptionMethod Algorithm= "http://www.w3.org/2001/04/xmlenc#rsa-
                     1_5"/>
        <ds:KeyInfo>
          <wsse:SecurityTokenReference>
            <wsse:Reference
                     URI="http://www.certRepository/ X509Certs/theClientCert"/>
```

```
19              </wsse:SecurityTokenReference>
20            </ds:KeyInfo>
21            <xenc:CipherData>
22              <xenc:CipherValue>asdsdkjhhj278yasdf...  </xenc:CipherValue>
23            </xenc:CipherData>
24          </xenc:EncryptedKey>
25          <ds:Signature>
26            <ds:SignedInfo>
27              <ds:CanonicalizationMethod Algorithm="http://www.w3.org/2001/10/xml-
                          exc-c14n#"/>
28              <ds:SignatureMethod Algorithm="http://www.w3.org/2000/09/xmldsig#rsa-
                          sha1"/>
29              <ds:Reference URI="#body">
30                <ds:DigestMethod
                          Algorithm="http://www.w3.org/2000/09/xmldsig#sha1"/>
31                <ds:DigestValue>KLSDF72365FDA...</ds:DigestValue>
32              </ds:Reference>
33            </ds:SignedInfo>
34            <ds:SignatureValue>Adfab234asd...</ds:SignatureValue>
35            <ds:KeyInfo>
36              <wsse:SecurityTokenReference>
37                <wsse:Reference
                          URI="http://www.certRepository/X509Certs/authServerCert"/>
38              </wsse:SecurityTokenReference>
39            </ds:KeyInfo>
40          </ds:Signature>
41        </wsse:Security>
42      </SOAP:Header>
43      <SOAP:Body wsu:Id="body">
44        <acl:AuthorizationResponse>
45          <acl:Services>
46            <acl:Service URI="xc2i://j9.mil/juo-jsaf">
47              <acl:Role id="White">
48                <acl:Token>
49                  <enc:EncryptedData Type="http://www.w3.org/2001/04/xmlenc#Content"
50                    xmlns:enc="http://www.w3.org/2001/04/xmlenc#">
51                    <enc:encryptionMethod
52                      Algorithm="http://www.w3.org/2001/04/  xmlenc#aes128-cbc>
53    <!--Implicitly use symmetric key encrypted above.-->
54                    <enc:CipherData>
55                      <enc:CipherValue>  AB342311CE93...</enc:CipherValue>
56                    </enc:CipherData>
57                  </enc:EncryptedData>
58                </acl:Token>
59              </acl:Role>
60            </acl:Service>
61          </acl:Services>
62        </acl:AuthorizationResponse>
63      </SOAP:Body>
64    </SOAP:Envelope>
```

This is the response to the previous query. Lines 14-24 contain an encrypted symmetric key used to encrypt the security tokens found later. This symmetric key is encrypted using the client's public key, which was extracted from the certificate provided with the request. Lines 25-40 contain a digital signature across the body of the message. The message is signed using the authenticating server's private key. Lines 35-39 reference the server's certificate, allowing a receiving client to verify the signature. Line 47 lists the role for which a token follows. Finally, lines 48-58 contain the actual encrypted token.

Example Unencrypted Token

```
<!--Here's the structure of the Token element
 which is extracted from the EncryptedData element. -->
<acl:Token
  xmlns:ds="http://www.w3.org/2000/09/xmldsig#"
  xmlns:xenc="http://www.w3.org/2001/04/xmlenc#"
```

```
 6      xmlns:wsse="http://docs.oasis-open.org/wss/2004/01/
                          oasis-200401-wsswssecurity-secext-1.0.xsd"
 7      xmlns:wsu="http://docs.oasis-open.org/wss/2004/01/
                          oasis-200401-wsswssecurity-utility-1.0.xsd"
 8      xmlns:acl="http://www.xmsf.com/xc2i/access-control">
 9      <acl:TokenHeader>
10        <wsse:Security>
11          <wsu:Timestamp wsu:Id="tok1Tstamp">
12            <wsu:Created>2004-05-21T08:42:00Z</wsu:Created>
13          </wsu:Timestamp>
14          <wsse:BinarySecurityToken
15            ValueType="...#X509v3"
16            EncodingType=
                "http://www.w3.org/2000/09/xmldsig#base64Binary"
17            wsu:Id="auth509Token">
18            KMHASDFKHasdf234jha...
19          </wsse:BinarySecurityToken>
20          <!--Signature for Body-->
21          <ds:Signature>
22            <ds:SignedInfo>
23              <ds:CanonicalizationMethod Algorithm=
                          "http://www.w3.org/2001/10/xml-exc-c14n#"/>
24              <ds:SignatureMethod Algorithm=
                          "http://www.w3.org/2000/09/xmldsig#rsa-sha1"/>
25              <ds:Reference URI="#tok1Body">
26                <ds:DigestMethod Algorithm=
                          "http://www.w3.org/2000/09/xmldsig#sha1"/>
27                <ds:DigestValue>KLSDF72365FDA...</ds:DigestValue>
28              </ds:Reference>
29            </ds:SignedInfo>
30            <ds:SignatureValue>Adfab234asd...</ds:SignatureValue>
31            <ds:KeyInfo>
32              <wsse:SecurityTokenReference>
33                <wsse:Reference URI="#auth509Token"/>
34              </wsse:SecurityTokenReference>
35            </ds:KeyInfo>
36          </ds:Signature>
37        </wsse:Security>
38      </acl:TokenHeader>
39      <acl:TokenBody wsu:Id="tok1Body">
40        <!--Client Username-->
41        <wsse:UsernameToken>
42          <wsse:Username>Me</wsse:Username>
43        </wsse:UsernameToken>
44        <!--Certificate for client-->
45        <wsse:BinarySecurityToken
46            ValueType="...#X509v3"
47             EncodingType=
                "http://www.w3.org/2000/09/xmldsig#base64Binary"
48            wsu:Id="client509Token">
49          KMHASDFKHasdf234jha...
50        </wsse:BinarySecurityToken>
51        <!--Unique identifier for the service -->
52        <acl:ServiceURI>xc2i://j9.mil/juo-jsaf</acl:ServiceURI>
53        <!--Role-->
54        <acl:Role>White</acl:Role>
55      </acl:TokenBody>
56    </acl:Token>
```

This is what the token looks like unencrypted. Note that lines 14-19 contain the authentication server's certificate and lines 45-50 contain the client's certificate. This allows the service to verify the identity of both the signing authority and the connecting client. The token itself contains the client's username on lines 41-43, the aforementioned client certificate, the service to which it applies on line 52, and the authenticated role on line 54.

WSIM

The need for a comprehensive approach to WSIM became apparent in the early design stages for

XC2I. In large scale simulations like JUO/JSAF, updates are potentially being sent by thousands, or even hundreds of thousands of entities spread throughout the battlespace. These updates generate more traffic than can be accommodated by all but the highest bandwidth connections, making it difficult or impossible to forward all data over a wide area network. The JUO/JSAF federation deals with this traffic glut through creative use of HLA Data Distribution Management (DDM) and by traffic shaping via the RTI-s simply to manage throughput on a LAN. This solution was untenable for XC2I for several reasons. First, the XC2I architecture was meant to provide an abstract interface to C2I simulation systems regardless of their underlying implementations. Second, because there is not standard practice for implementing an HLA DDM scheme across simulations, we could not count on the existence of applicable region information. Finally, the XC2I solution needed to be adaptable to non-HLA data sources, meaning that any solution that could not be applied to DIS and other simulation interoperability protocols was unacceptable.

Based on the unique needs of the C2I viewer space, it was decided that two separate levels of interest management would be required. The first, AOIM, would focus on limiting subscription to the geographically relevant subset of specific entities and types, and further filtering on visible, or otherwise relevant movement and update rates. The second, AGIM, would focus on aggregated data, an example of which is representing a number of units as a single coherent battle grouping such as a brigade or battalion. C2IML was developed to encapsulate these IM schemes. Developed as an interpretation of the C2IEDM specification in XML, C2IML provides the syntax for describing subscription in terms of Interest Expressions (IE) that detail the XC2I user's AOI and AGI.

AOIM

AOIM is based primarily upon geographic location, object type, and object id. However, C2IML has been designed with facilities to allow further filtering of AOI based upon update frequency and geographical deltas.

In the viewer currently under development, the user subscribes to types of entities in a geographic region using a GUI. We define this geographic region as the subscribing viewbox. For simplicity, all IEs have at most one viewbox. All other operands are interpreted to be subscriptions within the viewbox. The current language assumes that IEs are additive, i.e. that each subscription for a given viewbox adds to any previous subscriptions for the same viewbox. The following restrictions are enforced for the limited scope of the current viewer:

- A user can only subscribe to entities in the current viewbox.
- If an entity of interest moves out of the viewbox ("out of scope"), its updates won't be delivered again until it's back in scope, but the subscription will remain in effect. This is enforced by the viewer, not by C2IML.

The rationale behind filtering AOI via geographical deltas was simple: within the context of the viewer, any movement too subtle to be seen at the user's current zoom level wasted bandwidth if sent. Similarly, update frequency could be used to filter out data updated more frequently than the screen could be refreshed, or alternately could be used to arbitrarily throttle back updates to a level supported by the available bandwidth. While a user would choose their viewbox and any specific entities and types to which they wished to subscribe, geographical deltas and update frequency parameters would likely only ever be used transparently by the XC2I system itself. The example below is a C2IML IE illustrating many of these principles.

```
1 <c2iml:InterestExpression xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
2       xsi:schemaLocation="file://./c2iml.xsd"
3       xmlns:c2iml="http://www.xmsf.com/xc2i/c2iml">
4       <c2iml:Viewbox>
5             <c2iml:CornerPosition lat="30.720" lon="-98.588"/>
6             <c2iml:CornerPosition lat="31.720" lon="-97.588"/>
7             <c2iml:BoxHeight baseAltitude="0" height="9000"/>
8       </c2iml:Viewbox>
9       <c2iml:GeodeltaFilter distance="1000"/>
10      <c2iml:TemporalFilter>
11            <c2iml:Time>300</c2iml:Time>
12            <c2iml:Update>10</c2iml:Update>
13      </c2iml:TemporalFilter>
14      <c2iml:ObjectTypeList>
15            <c2iml:ObjectType id="1"/>
16            <c2iml:ObjectType id="2"/>
17            <c2iml:ObjectType id="4"/>
18      </c2iml:ObjectTypeList>
19      <c2iml:ObjectItemList>
20            <c2iml:ObjectItem id="356"/>
21      </c2iml:ObjectItemList>
22 </c2iml:InterestExpression>
```

This example bears some explanation. Lines 4-8 define a geographical Viewbox giving the upper left and lower right corners in terms of their latitude and longitude (5-6), the base height of the bottom of the bounding box, and the height of the box(7). This information is sufficient to define a geographically unique volume in space. Note that the BoxHeight element is optional. If not included it is assumed that the area of interest includes all heights above and below sea level within the rectangle defined by the two bounding corners.

Following the Viewbox is a series of general ObjectType entries (14-18). The ObjectType element is defined on lines 37-44 of the Schema. This describes an interest in particular classes of entities. After the class interest statement is a separate list of individual entities of interest(19).

The GeodeltaFilter on line 9 defines a minimum geographical granularity filter, asking that updates that involve a delta less than this distance not be sent. This filter would be used to limit traffic to a viewer to changes which could be seen at the current zoom resolution. A TemporalFilter is used on lines 10-13. The TemporalFilter sets a filter on the rate at which updates are to be passed to the client. In this case, line 11 asks that updates be filtered if they are received more than once every 300 milliseconds, and line 12 asks for only every tenth update.

AGIM

AGIM is a new concept developed for this viewer allowing a user to see aggregated views of individual entities. This concept is most applicable to force-on-force simulations. AGIM has some unique challenges, including deriving the unit order of battle when it is not explicitly provided and determining the location at which to display the aggregated entity. It also has some clear advantages in the C2I space, especially when dealing with large force-on-force simulations. If a user is only interested in seeing and interacting with an aggregate, updates need only be sent to the XC2I client for the entire aggregate. By placing this functionality into the WSIM architecture bandwidth is drastically reduced and processing is offloaded from the client to the machines hosting the web services, which could be clustered or load-balanced. AGIM support is application specific and is expressed in C2IML using ObjectType and ObjectItem elements. The actual aggregation of individual entities must be either supported by the underlying simulation or the layered web services acting as intermediaries.

Future Work

While the ACL and architecture have been prototyped, shortcomings of the Web Services standards and work being done by the OASIS standards body indicate that the current work may be superseded by a significantly different message format, such as the eXtensible Access Control Meta Language (XACML). However, the fundamental architecture presented in this document will continue to be appropriate to the application. Additionally, the WSIM implementation currently has only preliminary support for an HLA 1.3 data feed. Extending the scope to include interchangeable HLA 1.3, 1516, and DIS feeds would help prove the viability of the architecture. Finally, exchanging the current GUI front-end for a cross-platform browser-launchable interface, perhaps written in Java, would greatly increase the flexibility of the XC2I application. While the WSIM in particular was accepted in the broader M&S and IT community and resulted in several referenced publications of the XMSF group, the J9/JFCOM-sponsored project was terminated in early Spring 2004 due to redirection of funds in support of the war in Iraq.

5.3 Conclusions

The current paradigm of co-locating participants in distributed simulation events has become outdated and costly. Current methods for allowing truly distributed participation require extensive configuration and end-to-end control of the networks involved. If simulation participation is to be truly distributed and flexible, remote users must be able to easily configure and run clients without extensive knowledge of the underlying systems while maintaining both security and performance. We believe that the layered web services approach taken by XC2I is a positive step in this direction. Moreover, replacing proprietary solutions with open standards solutions, in particular for the visualization components, is mandatory in the context of XMSF.

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6 COMMUNITY OUTREACH AND EDUCATION

6.1 Conference Papers

Don Brutzman, Andreas Tolk: "JSB Composability and Web Services Interoperability via Extensible Modeling & Simulation Framework (XMSF) and Model Driven Architecture (MDA)," Society of Photo-Optical Instrumentation Engineers (SPIE) Referenced Series: *Proceedings of the Conference Enabling Technologies for Simulation Sciences VIII, Defense and Security, Orlando, FL,* April 2004

J. Mark Pullen, Ryan Brunton, Don Brutzman, David Drake, Michael Hieb, Katherine Morse, Andreas Tolk: "Using Web Services to Integrate Heterogeneous Simulations in a Grid Environment", Computational Science - ICCS 2004: *4th International Conference, Kraków, Poland, June 6-9, Proceedings, Part III, Series: Lecture Notes in Computer Science, Publisher: Springer-Verlag Heidelberg, pp. 835 – 847*, 2004

Andreas Tolk: "Composable Mission Spaces and M&S Repositories – Applicability of Open Standards," Spring Simulation Interoperability Workshop 2004, Paper 04S-SIW-009, Washington, D.C., April 2004

Michael R. Hieb, J. Mark Pullen, William P. Sudnikovich, Andreas Tolk: "Developing Battle Management Language into a Web Service," Spring Simulation Interoperability Workshop 2004, Paper 04S-SIW-113, Washington, D.C., April 2004

Curtis Blais: "Extensible Modeling and Simulation Framework (XMSF) Exemplars in Analytic Combat Modeling," Spring Simulation Interoperability Workshop 2004, Paper 04S-SIW-142, Washington, D.C., April 2004

Andreas Tolk: "Moving towards a Lingua Franca for M&S and C3I – Developments concerning the C2IEDM," European Simulation Interoperability Workshop 2004, Paper 04E-SIW-016, pp. 91 – 102, Edinburgh, Scotland, June 2004

Andreas Tolk, Kevin Galvin, Michael Hieb, Lionel Khimeche: "Coalition Battle Management Language," Fall Simulation Interoperability Workshop 2004, Paper 04F-SIW-103, pp. 724-735, Orlando, Florida, September 2004

Charles Turnitsa, Sai Kovvuri, Andreas Tolk, Liam DeMasi, Verlynda Dobbs, Bill Sudnikovich: "Lessons Learned from C2IEDM Mappings within XBML," Fall Simulation Interoperability Workshop 2004, Paper 04F-SIW-111, pp. 792-801, Orlando, Florida, September 2004

Michael R. Hieb, J. Mark Pullen, William P. Sudnikovich, Andreas Tolk: "Extensible Battle Management Language (XBML): A Methodology for Web Enabling Command and Control for Network Centric Warfare," 2004 Command and Control Research and Technology Symposium, San Diego, CA, June 2004 *(also presented during the International CCRTS, Copenhagen, Denmark, September 2004)*

Michael R. Hieb, Andreas Tolk, William P. Sudnikovich, J. Mark Pullen: “Developing Extensible Battle Management Language to Enable Coalition Interoperability,” European Simulation Interoperability Workshop 2004, Paper 04E-SIW-064, pp. 382 – 392, Edinburgh, Scotland, June 2004

Andreas Tolk, John J. Garcia: “Model-based Data Management for Mediation Services for Intelligent Software Agents,” Symposium on Intelligent Software Systems for the New Infostructure, 16th International Conference on Systems Research, Informatics and Cybernetics (InterSymp-2004), Baden-Baden, Germany, July 2004

Andreas Tolk: “Operational Modeling & Simulation Services in Military Service-oriented Architectures - A White Paper summarizing related Concepts,” 6th Office of Naval Research (ONR) Conference/Workshop on Decision Support, US Marine Corps Headquarters, Quantico, VA, September 2004 *(also presented during the Workshop on Distributed Simulation & Virtual Environments, NTU, Singapore, September 2004)*

Andreas Tolk: “Metamodels and Mappings – Ending the Interoperability War,” Fall Simulation Interoperability Workshop 2004, Paper 04F-SIW-105, pp. 748-761, Orlando, Florida, September 2004

Curtis Blais and Lee Lacy: "Semantic Web: Implications for Modeling and Simulation System Interoperability," Fall Simulation Interoperability Workshop 2004, Paper 04F-SIW-030, Orlando, Florida, September 2004

Andreas Tolk, Michael Hieb, Kevin Galvin, Lionel Khimeche: “Merging National Battle Management Language Initiatives for NATO Projects,” Paper 12, Proceedings RTA/MSG Conference on *“M&S to address NATO’s new and existing Military Requirements”*, Koblenz, Germany, October 2004

Katherine L. Morse, Andreas Tolk, J. Mark Pullen, Don Brutzman: “XMSF as an Enabler for NATO M&S,” Paper 13, Proceedings RTA/MSG Conference on *“M&S to address NATO’s new and existing Military Requirements”*, Koblenz, Germany, October 2004

Katherine L. Morse, Ryan Brunton, J. Mark Pullen, Priscilla McAndrews, Andreas Tolk, James Muguira: “An Architecture for Web Services Based Interest Management in Real Time Distributed Simulation,” Proceedings of the 8th IEEE International Symposium on Distributed Simulation and Real Time Applications (DS-RT 2004), Budapest, Hungary, October 2004

Dennis Moen, J. Mark Pullen, and Fei Zhao, "Implementation of Host-based Overlay Multicast to Support of Web Based Services for RT-DVS," Proceedings of the Eighth IEEE Workshop on Distributed Simulation and Real-Time Applications (DS-RT 2004), Budapest, Hungary, October 2004

S. K. Numrich, Michael R. Hieb, Andreas Tolk: "M&S in the GIG Environment: An Expanded View of Distributing Simulation," Proceedings of the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC), Tutorial Paper, Orlando, Florida, December 2004

Andreas Tolk, James A. Muguira: "M&S within the Model Driven Architecture," Proceedings of the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC), Paper 1477, Orlando, Florida, December 2004

Andreas Tolk: "XML Mediation Services utilizing Model Based Data Management," 2004 Winter Simulation Conference, SCS, Washington, DC, December 2004

The following papers were prepared under funding from OPNAV N81, but promote XMSF concepts:

Phillip E. Pournelle, Curtis Blais, Don Brutzman: "A Transformational Framework for Design, Development, and Integration of Simulation Models," Fall Simulation Interoperability Workshop 2004, Paper 04S-SIW-019, Orlando, Florida, September 2004

Arnold Buss: "Simkit Analysis Workbench for Rapid Construction of Modeling and Simulation Components," Fall Simulation Interoperability Workshop 2004, Paper 04S-SIW-020, Orlando, Florida, September 2004

Arnold Buss, John Ruck, Don Brutzman: "Using XMSF Web Services for Joint Modeling and Analysis," Fall Simulation Interoperability Workshop 2004, Paper 04S-SIW-021, Orlando, Florida, September 2004

6.2 Tutorials

Presentations at the XMSF Developers' Deep-Dive Workshop, Naval Postgraduate School, Monterey, CA, August 2004:

- Alan Hudson, Justin Couch: "Xj3D Browser"
- Alan Hudson, Don Brutzman: "XSBC XML Schema Binary Compression"
- Don Brutzman, Duane Davis, Scott Rosetti: "AUV Workbench"
- Mark Pullen: "Network EducationWare (NEW) as XMSF Infrastructure"
- Andreas Tolk: "XC2I Project and Viewer Overview"
- Katherine Morse: "Web Service Interest Management (WSIM) Design and Language"
- Mark Pullen: "WSIM Prototype"
- Katherine Morse: "Role-Based Access Control (RBAC) Protocol"

Presentation made at VMASC and available online, 19 November 04

- Mark Pullen: "Overlay Multicast and its Application for Advanced Distributed Simulation"

Tutorial during the I/ITSEC 2004

- Sue Numrich, Mike Hieb, Andreas Tolk: "M&S in the GIG Environment"

6.3 Workshops

Presentations at the 2004 Web3D Conference, Monterey, CA, April 2004:

- Don Brutzman: “Extensible Modeling and Simulation Framework (XMSF) Overview”

Presentations at the 2nd Annual Workshop on Web-enabled Modeling and Simulation, Washington, D.C., October 2004:

- Don Brutzman: "Extensible Interoperability Framework (X3D and XMSF)"
- Andreas Tolk: "Web-based Modeling and Simulation and the SISO"
- Don Brutzman: "Web-based Modeling and Simulation and the Web3D Consortium"
- Andreas Tolk: "Metamodels and Mappings -- Ending the Interoperability War"
- Katherine Morse: "Layered Web Services for M&S"
- Charles Turnitsa: "Lessons Learned on a Service-Oriented Architecture Employed in Implementing a Web Enabled C2I Visualization Tool for Joint Forces Command (JFCOM)”

6.4 Other Activities

Presentations at the 2004 MOVES Open House, Naval Postgraduate School, Monterey, CA, August 2004:

- Curtis Blais: "Semantic Web Technologies for Military M&S"
- Don Brutzman, Mark Pullen, Andreas Tolk, Katherine Morse: "Extensible Modeling and Simulation Framework (XMSF) Project Update"
- Don Brutzman, Mark Pullen, Andreas Tolk: "Quick-look Report on the XMSF Developers' Deep-Dive Workshop"
- Katherine Morse: "XMSF Profiles"
- Maj Glenn Hodges: "Designing a Common Interchange Format for Unit Data using C2IEDM and XSLT"
- LT Scott Rosetti: "XMSF Exemplar Projects: Sonar Visualization"
- Don McGregor, LT Matt Mackay, Don Brutzman: "XMSF Exemplar Projects: XML-based Tactical Chat (XTC)"
- CDR Duane Davis: "XMSF Exemplar Projects: Autonomous Underwater Vehicle (AUV) Workbench"
- LT Terry Norbraten: "XMSF Exemplar Projects: XML Schema-based Binary Compression (XSBC)"
- Andreas Tolk: "XC2I Overview and Viewer/Controller Technology"
- Katherine Morse: "XC2I Web Service Interest Management"
- Mark Pullen: "XC2I Application of XMSF Overlay Multicast"

Presentations during the NATO M&S Conference on “M&S to address NATO’s new and existing Military Requirements”, held in Koblenz, Germany, 7-8 October 2004

- A. Tolk, M. Hieb, K. Galvin, L. Khimeche: “Merging National Battle Management Language Initiatives for NATO Projects”
- K. Morse, A. Tolk, M. Pullen, D. Brutzman: “XMSF as an Enabler for NATO M&S”

Presentation during the Workshop on Distributed Simulation & Virtual Environments at the National Technical University (NTU) of Singapore

- M. Pullen: “Web Services as a Mechanism to Integrate Heterogeneous Simulations and C4I Systems”
- A. Tolk: “M&S Services in Operational Service Oriented Architectures”

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GLOSSARY OF TERMS AND ACRONYMS

ACL	Access Control Language
AGIM	Aggregation Interest Management
AMSO	Army Modeling and Simulation Office
ASD	Assistant Secretary of Defense
BCSE	US Army Battle Command, Simulation and Experimentation Directorate
BPEL4WS	Business Process Execution Language for Web Services
C2IEDM	Command and Control Information Exchange Data Model
C4I	Command, Control, Communications, Computers, and Intelligence
CINC	Commander in Chief
CNAD	Conference of National Armaments Directors
CoABS	Control of Agent Based Systems
COI	Community of Interest
COR	Contracting Officer's Representative
CWM	Common Warehouse Metamodel
DAML	DARPA Agent Markup Language
DARPA	Defense Advanced Research Projects Agency
DCEE	Distributed Continuous Experimentation Environment
DDM	Data Distribution Management
DIS	Distributed Interactive Simulation
DISA	Defense Information Systems Agency
DMSO	Defense Modeling and Simulation Office
DoD	Department of Defense
DoDAF	DoD Architectural Framework
DON CIO	Department of the Navy Chief Information Officer
DTRA	Defense Threat Reduction Agency
EA	Enterprise Architecture
ERDC	US Army Engineer Research and Development Center
ES	Enterprise Services
FAST	Flexible Asymmetric Simulation Technologies
FEC	Forward Error Correction
FEDEP	Federation Development and Execution Process
FTE	Full-Time Equivalent
GES	Grid Enterprise Services
GIG	Global Information Grid
GMU	George Mason University
GSA	General Services Administration
HF	Horizontal Fusion
HLA	High-Level Architecture
HTTP	Hyper Text Transfer Protocol
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IGMP	Internet Group Management Protocol
I/ITSEC	Interservice/Industry Training, Simulation, and Education Conference

IP	Intellectual Property
IPR	In Progress Review
ISO	International Standards Organization
IT	Information Technology
JFCOM	Joint Forces Command
JTA	Joint Technical Architecture
M&S	Modeling and Simulation
MMF	Mission-to-Means Framework
MOF	Meta Object Facility
MOOTW	Military Operations Other Than War
MOVES	Modeling, Virtual Environments, and Simulation
MPLS	Multiprotocol Label Switching
MST	Minimum-weight Spanning Tree
MTF	Message Text Format
NATO	North Atlantic Treaty Organization
NC3A	NATO Consultation, Command and Control Agency
NCCP	Network Centric Capabilities Pilot
NCES	Net-Centric Enterprise Services
NEW	Network EducationWare
NPS	Naval Postgraduate School
ODU	Old Dominion University
OGC	Open Geospatial Consortium
OIL	Ontology Inference Layer
OSD	Office of the Secretary of Defense
OSI	Open System Interconnection
OWL	Web Ontology Language
PIM	Platform Independent Model
PKI	Public Key Infrastructure
PSM	Platform Specific Model
QoS	Quality of Service
RBAC	Role Based Access Control
RDF	Resource Description Framework
RDF-S	RDF Schemas
RF	Radio Frequency
RT-DVS	Real-Time Distributed Virtual Simulation
RTI	Run-Time Infrastructure
SAIC	Science Applications International Corporation
SGML	Standard Generalized Markup Language
SISO	Simulation Interoperability Standards Organization
SIW	Simulation Interoperability Workshop
SMART	Simulation, Modeling, Acquisition, Requirements, and Training
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SOW	Statement of Work
SRMP	Selectively Reliable Multicast Protocol
STF	SEDRIS Transmittal Format

STRATCOM	Strategic Command
TENA	Test and Training Enabling Architecture
UDDI	Universal Description, Discovery, and Integration
UML	Unified Modeling Language
VMASC	Virginia Modeling, Analysis, and Simulation Center
W3C	World Wide Web Consortium
WE-RTI	Web-Enabled RTI
WSDL	Web Services Description Language
WSIM	Web Services Interest Management
XBML	Extensible Battle Management Language
XC2I	Experimentation Command and Control Interface
XML	Extensible Markup Language
XMSF	Extensible Modeling and Simulation Framework
XOM	XMSF Overlay Multicast
XSLT	Extensible Stylesheet Language Transformations
XTC	XML-based Tactical Chat

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